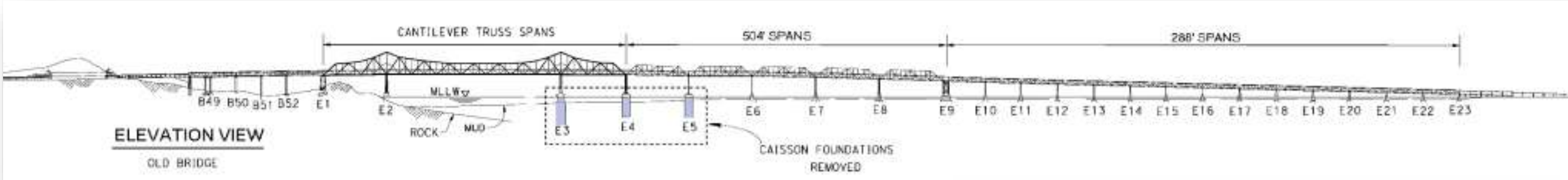
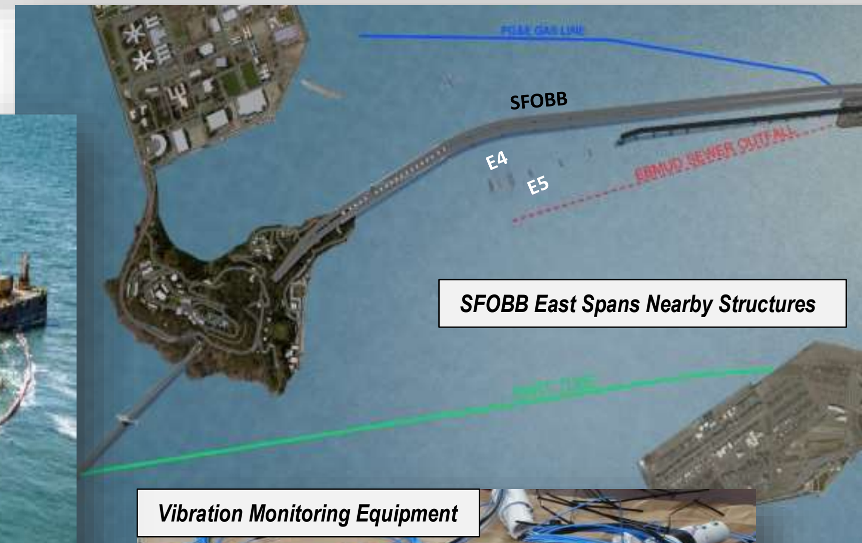
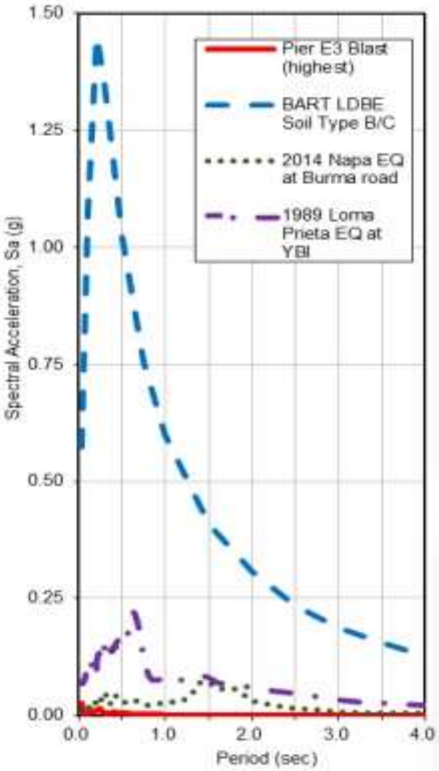


SFOBB Old Spans Piers E3-E5 Implosions Project Report
January 2017

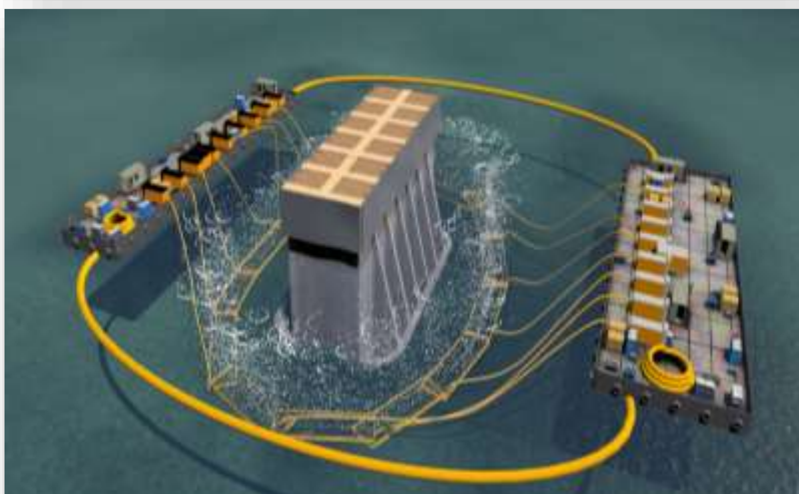


SFOBB East Spans Nearby Structures



Actual Pier Implosion

Vibration Monitoring Equipment



Pier with Blast Attenuation System, Debris Collection Boom, and Pressure/ Noise Sensors Deployment

Caged Fish Study

Water Quality and Sediment Sampling

San Francisco–Oakland Bay Bridge
East Span Seismic Safety Project

SFOBB Old Spans Piers E3-E5 Implosions Project Report

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Table of Contents

Appendices

List of Figures

List of Tables

List of Abbreviated Terms

$\mu Pa^2\text{-}s^{-1}$	micropascal squared per second
AMP	Avian Monitoring Plan
APS	Advanced Planning Study
BART	Bay Area Rapid Transit
BAS	Blast Attenuation System
BATA	Bay Area Toll Authority
Bay	San Francisco Bay
BCDC	Bay Conservation Development Commission
BO	Biological Opinion
CDB	Contract Drilling and Blasting LLC
CDFW	California Department of Fish and Wildlife
CEC-Silverado	California Engineering Contractors–Silverado Joint Venture
CHP	California Highway Patrol
CMGC	Construction Manager/General Contractor program
CO	Capital Outlay
COS	Capital Outlay Support
cSEL	cumulative sound exposure levels
CSMIP	California Strong Motion Instrumentation Program
CTC	California Transportation Commission
dB	decibel(s)
dBe	cumulative sound pressure level units of decibels
dBp	sound pressure level units of decibels
DC	direct current
Δ	change in
Department	California Department of Transportation
EBMUD	East Bay Municipal Utility District
EMI	Earth Mechanics, Inc.
FEIS	Final Environmental Impact Statement
FHWG	Fisheries Hydroacoustic Working Group
g	gravitational acceleration unit
GI	gastrointestinal
GMP	Guaranteed Maximum Price
HF	high frequency
Hz	hertz
IHA	Incidental Harassment Authorization
in/s	inches per second
ITP	Incidental Take Permit
K-M	Kiewit-Manson Joint Venture
LDBE	Lower Level Design Basis Earthquake
L_{peak}	peak level
MMEZ	Marine Mammal Exclusion Zone

MMMP	Marine Mammal Monitoring Program
MMO	marine mammal observer
MMPA	Marine Mammal Protection Act
MP	monitoring point
NAS	Naval Air Station
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
PDT	Project Development Team
PG&E	Pacific Gas and Electric Company
pH	hydrogen ion concentration
PPV	peak particle velocity
psi	pounds per square inch
psi-ms	psi per millisecond
PTS	Permanent Threshold Shift
RFP	Request for Proposals
RMS	root mean square
RWQCB	Regional Water Quality Control Board
SAP	Sampling and Analysis Plan
SEL	sound exposure level
SFOBB	San Francisco–Oakland Bay Bridge
SPL	sound pressure level
S/s	samples per second
SWRCB	State Water Resources Control Board
TBPOC	Toll Bridge Program Oversight Committee
TI	Treasure Island
TTS	Temporary Threshold Shift
USACE	United States Army Corps of Engineers
USBM	United States Bureau of Mines
USCG	United States Coast Guard
USFW	United States Fish and Wildlife Service
WQO	Water Quality Objectives
YBI	Yerba Buena Island

Chapter 1. Introduction and Background

1.1. Introduction

This report presents the results of the implosions of the old San Francisco–Oakland Bay Bridge (SFOBB) marine foundations Piers E3 through E5 that occurred in late fall 2015 (Pier E3) and 2016 (Piers E4 and E5). It documents the success of the work from an environmental, design, and construction project perspective. It presents information on design-construction planning as well as quantitative scientific results measured during and following the blast events. The report offers clear documentation that the removal of the old SFOBB East Spans marine piers should be continued using the method of implosion by highly controlled charges within a Blast Attenuation System (BAS). The blast events should occur during the months of September through December, the time window identified by natural resource agency specialists as a period when no listed species are expected to be near this part of the San Francisco Bay (Bay). This report projects a path forward to completing removal of the bridge piers, building on the pioneering work of the Piers E3 through E5 removal that optimized opportunities to minimize environmental impacts on the Bay at minimal total cost by employing advanced technologies.

1.2. Background

As part of the San Francisco–Oakland Bay Bridge East Spans Seismic Safety Project, the old lead paint-covered high steel structures and foundations are to be removed from the waters of the Bay as part of the original mitigation package, as documented in the Final Environmental Impact Statement (FEIS) (Department 2001) and permits dating back to 2001. For contracting purposes, removal of the old East Spans was divided into three major components related to values associated with the work, appropriate sequencing, and similar types of work, specifically: 1) the very complex 0.5-mile-long steel cantilever truss, located very near the new bridge on Yerba Buena Island (YBI) above a primary shipping channel, which also included removal of the 1,725-ft. long Double Deck Temporary Bypass Structure (the S-curve); 2) the string of five 504-foot and fourteen 288-foot steel trusses; and 3) the marine foundations, Pier E2 through E22. Figure 1-1 shows the old East Spans layout. The Toll Bridge Program Oversight Committee (TBPOC) has proposed retaining Piers E2 (near YBI), E19 through E22 (near the Oakland shore), and land-based Pier E23 for historic purposes and to provide opportunities for the public to access the Bay. Interactions between the TBPOC and the Bay resource agencies have begun in this regard.

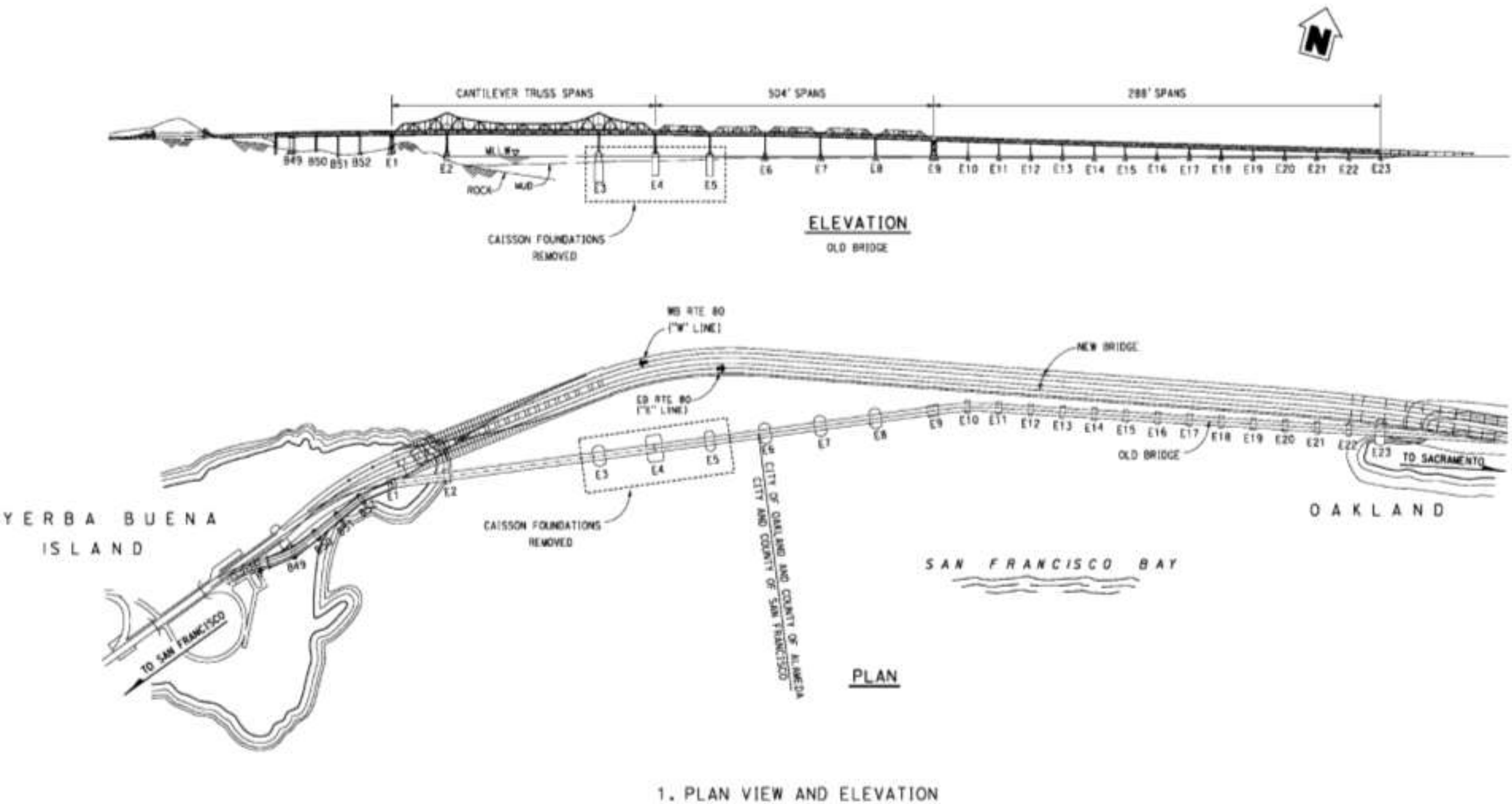

Figure 1-1. Old San Francisco–Oakland Bay Bridge East Spans Layout

The marine foundations are two basic types: concrete caisson and timber pile. The caissons are at Piers E2, E3, E4, and E5. The caissons are made up of many reinforced concrete walls that range from 3 to 4 feet in thickness, spaced approximately 20 feet on centers, creating a network of open cells that extend as deep as 275 feet vertically at Pier E3. The timber pile foundations are at Piers E6 through E22, and even the on-shore Pier E23. The piles range in length from 85 to 120 feet, are 18 inches in diameter at their tops and taper down in size as they extend downward. The number of piles per foundation varies, from 298 piles at the foundations supporting the 288-foot trusses to 625 piles at Pier E9. The pile tops are held together by a concrete slab. On top of each concrete slab is a reinforced concrete cellular structure that extends from the slab to above the water surface. Figure 1-2 shows a representative image of both types of foundations. Figure 1-3 shows Pier E3 being prepared for blasting, with Piers E4 and E5 prior to removal of the bridge superstructure.

The piers are being removed from the top down to an elevation of 3 feet below the natural Bay mudline. That elevation has been determined for each pier specifically because the water depth and natural Bay mudline vary along the bridge. Water depths are as great as 75 feet near Pier E3 and less than 10 feet near Pier E22. A pier is accepted as removed from the waters of the Bay after all the imploded concrete rubble is removed to 3 feet below natural Bay mudline elevations. The project team has made commitments to continue to perform subsurface surveys at the pier sites, documenting that the scour holes are filling in with natural materials.

The successful deconstruction of the cantilever truss was completed in 2015, and the successful removal of the last of the 504-foot-long trusses was completed in 2016. Currently, removal of the 288-foot-long trusses is well ahead of schedule, and the first three and largest of the marine piers were removed successfully from the Bay in 2015 (Pier E3) and 2016 (Piers E4 and E5). A summary schedule for removal of the old spans is shown in Figure 1-4. Rows 1 through 3 show the schedule of the cantilever removal that was finished early. Rows 4 through 7 show the 504- and 288-foot truss removal schedule that is currently on track to finish early. Rows 8 through 11 show two schedules for removal of Piers E3 through E18: an as-bid schedule for removal of Piers E3 through E18 is shown in row 9, and a potential early completion schedule for the same Piers E3 through E18 is shown in rows 10 and 11. The project team successfully completed the cantilever removal on an accelerated schedule, thus allowing an early finish of the 504- and 288-foot truss removal, which in turn is establishing conditions so that early completion of Piers E6 through E18 is possible if work to remove concrete above the water can be started early.

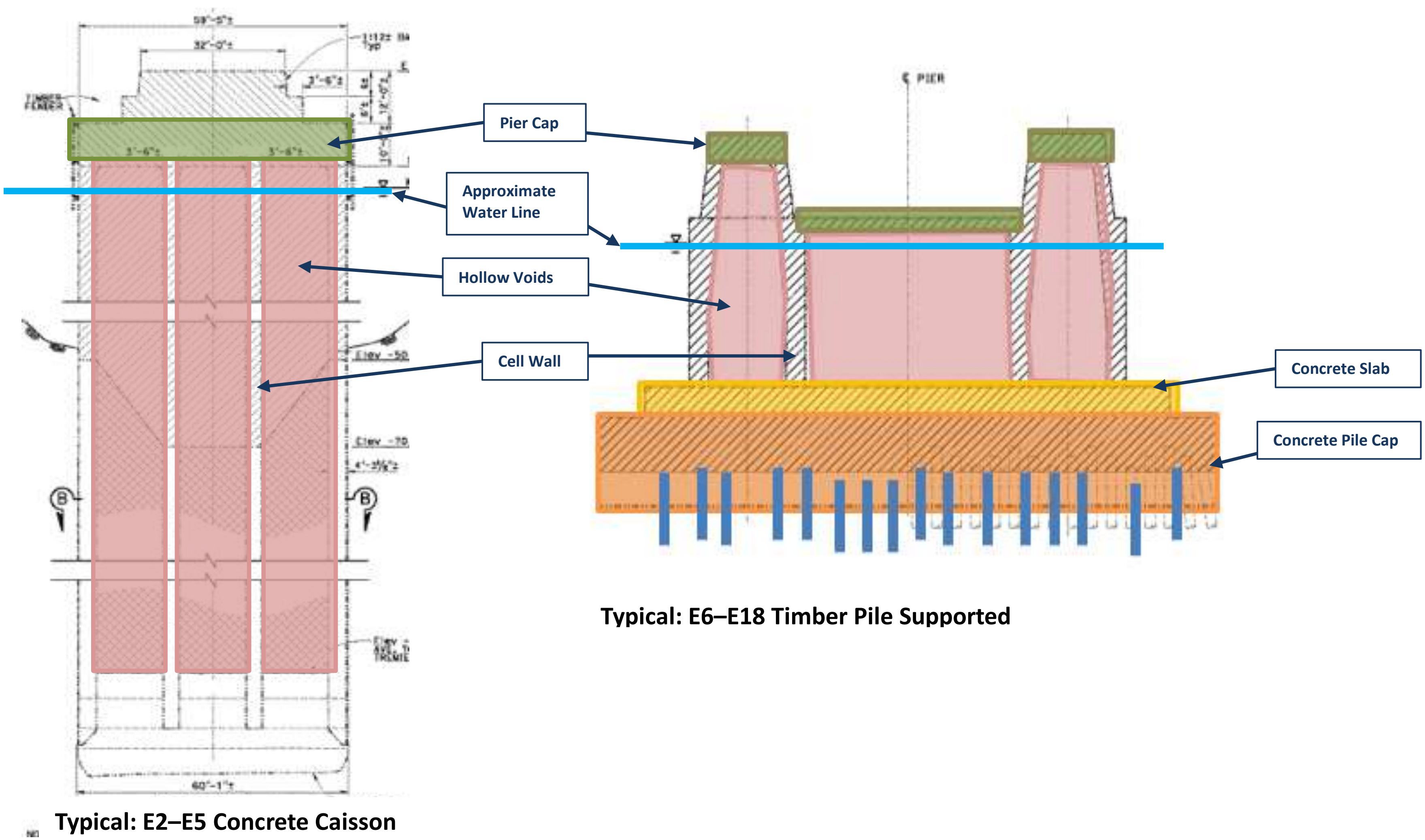

Figure 1-2. Types of SFOBB East Span Marine Piers

Figure 1-3. Preparation of Pier E3 for Implosion.

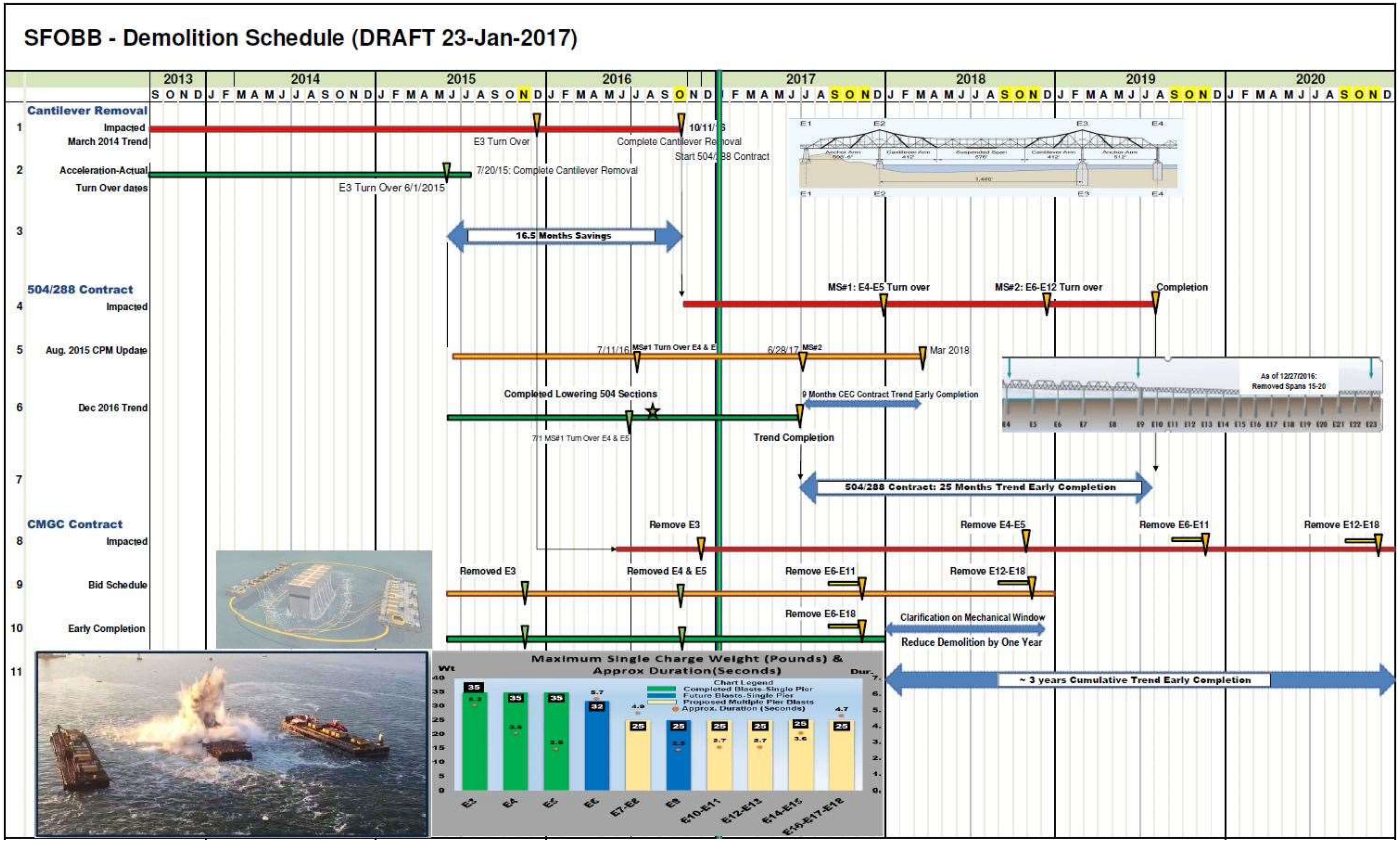

Figure 1-4. Old East Spans Removal Summary Schedule

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Environmental conditions in the Bay, knowledge of those conditions, specific construction means and methods to be used, and interaction between all the above, have changed substantially since the beginning of the Toll Bridge Seismic Retrofit Program, in a large part because of the investment of actual field surveys, large-scale field demonstrations, and thoughtful consideration of the technical information resulting from work by the SFOBB East Spans project team. In cooperation with the California Department of Transportation (Department), the Bay Area Toll Authority (BATA), the California Transportation Commission (CTC), the Bay Conservation Development Commission (BCDC), the State Water Resources Control Board (SWRCB), the United States Army Corps of Engineers (USACE), the United States Coast Guard (USCG), the United States Fish and Wildlife Service (USFWS), the California Department of Fish and Wildlife (CDFW), the National Oceanic and Atmospheric Administration (NOAA), and the California Highway Patrol (CHP), three very large cellular bridge pier foundations (caissons) have been removed successfully from waters of the Bay.

In 2013, an Advanced Planning Study (APS) was released that incorporated a concept to implode SFOBB Pier E3. The APS suggested that by using highly controlled (with regards to type, size, and time delays between small blasts) explosive charges, an optimum removal technique could be used to remove the in-water piers. The result of this approach would be to minimize impact on the environment as well as expedite marine construction in and on the water, and thus even further reducing environmental impacts. Such an opportunity rarely exists with large transportation projects. The Department, the Toll Bridge Program (a collective of the Department, BATA, and the CTC), and many State and federal environmental recourse agencies agreed to conduct a demonstration project in fall 2015 on a single SFOBB pier (Pier E3), to verify the potential benefits of the proposed removal technique. The results of the Pier E3 demonstration project were very good with respect to environmental, design, and construction measures. Using similar technology in fall 2016, similar results were achieved from the Piers E4 and E5 removal, as documented in this and other reports.

The following chapters address several major items. Chapter 2 describes the “blast plan design” of the marine piers that fundamentally initiates the generation, propagation, and decay/attenuation of a resulting pressure wave, greatly reduced by incorporation of the concept of many small blasts as compared to a single large blast. Chapter 3 presents information on the BAS that further reduces the pressure wave by attenuating the magnitude and modifying the pressure waveform. Chapter 4 details the responses of nearby structures during the implosions: the new SFOBB East Spans, the East Bay Municipal Utility District (EBMUD) sewer outfall pipe, and the Bay Area Rapid Transit

(BART) Transbay Tube. Chapter 5 discusses the impact on environmental quality with respect to water and air quality. Chapter 6 describes the potential impact on wildlife associated with the potentially affected areas. Chapter 7 explains the effectiveness of the project team's means and methods of removing Piers E3 through E5. Chapter 8 summarizes and clearly presents conclusions about the completed work.

Chapter 2. Blast Plan Design

This chapter provides insight into the project development iterations and design process for both the Pier E3 Demonstration Project and the Marine Foundation Removal Project of Piers E4 to E18.

2.1. Background

On November 14, 2015, Pier E3 was imploded successfully through use of sequenced and controlled charges. On October 15 and 29, 2016, the Department and K-M repeated this success with removal of Piers E5 and E4. The removal of these foundations as designed and planned has proven that use of controlled charges for removal of the remaining marine foundations of the SFOBB can be done safely, is the most efficient removal method available, and will minimize impacts on environmental resources in the Bay.

2.2. Advanced Planning Study Design

Removal of the existing SFOBB using explosives was contemplated as early as 1997, in the early planning phases of the replacement alternative for the New Eastern Span project. The use of explosives to dismantle the existing bridge was not included in the FEIS (Department 2001) because of time constraints in the overall project schedule. Planning and design for removal of the existing SFOBB was restarted in early 2011, as completion of the New Eastern Span project neared. The Project Development Team (PDT) conducted an outreach to the demolition industry, to evaluate a variety of means and methods for removing the existing structure. The major alternatives considered included the following:

- Mechanical removal with excavators fitted with percussion hammers and mechanical shears within a cofferdam;
- Mechanical removal using the above option with some removal accomplished with wire saws within a cofferdam;
- Use of Expansive Grout with or without a cofferdam; and
- Controlled blasting techniques, using a BAS to reduce overpressures created by the blast.

After thorough evaluation of each alternative, removal of the foundations through blasting with controlled charges was recognized to possibly be both the most efficient means of removal and the alternative with the fewest impacts on the Bay's environmental resources. In September 2011, the PDT moved forward with further studies to substantiate the viability of controlled blasting methods for this project. Revey Associates, Inc. completed its study, Evaluation of Practical Methods for Deconstructing SFOBB Piers, on October 6, 2011 (Revey, 2011). This study was the basis for proceeding with controlled blasting as the preferred alternative and contained the following important conclusions:

- Controlled blasting methods could be used to safely demolish the piers of the old SFOBB;
- Controlled blasting methods could be designed to ensure an acceptable level of environmental compliance; and
- Because of the challenging and complex nature of the work, a qualification-based contracting method using a Request for Proposals (RFP) would be desirable.

Based on these conclusions, the PDT moved forward to seek approval from the TPBOC and regulatory agencies for a demonstration project to remove Pier E3 using controlled blasting methods. Pier E3 was chosen by the PDT because it was viewed as the most challenging pier to remove based on its depth in the water column, and it was the largest pier by volume. Earth Mechanics, Inc. (EMI) developed an Advanced Planning Study (APS) (Department 2013) design that focused on use of controlled blasting methods coupled with development of a BAS to reduce blast overpressures. Engineered Explosive Services LLC developed three separate blast designs for the APS, as shown in Table 2-1.

Table 2-1. Advanced Planning Study Blast Designs

	Plan 1	Plan 2	Plan 3
1. Maximum Pounds per Delay	79.8 lbs	40.8 lbs	20.4 lbs
2. Blast Hole Diameter	3"	4"	4"
3. Blast Holes Required:			
• Top Walls	98	98	135
• Buttresses	24	24	36
• Perimeter Wall	48	48	62
4. Blast Detonations	414 each	780 each	1493 each
5. Blast Delay per Deck	25 ms	25 ms	25 ms
6. Estimated Powder Factor	5.29 lbs/cy	5.94 lbs/cy	5.84 lbs/cy
Notes: Pumpable Blasting Agent Hydromite or Equal cy = cubic yards; lbs = pounds; ms = milliseconds			

2.3. Project Delivery and Contracting Methodology

2.3.1. Contruction Manager/General Contractor Program

On April 22, 2014, the Department advertised a Request for Qualifications for removal of all marine foundations through the pilot Construction Manager/General Contractor (CMGC) program. This innovative project delivery and contracting method allowed the PDT to seek the most qualified contractor based on criteria developed by the PDT before the selection process. The selected contractor was to become a part of the PDT and help to design the project during the preconstruction services phase. After design completion, the contractor and the Department were to develop estimates and risk registers, and negotiate a Guaranteed Maximum Price (GMP) for project construction. The CMGC process was ideal for the project for the following reasons:

- The PDT was able to use the experience of the contractor on marine foundation removal projects;
- The PDT was able to select a contractor with substantial experience in controlled blasting of marine structures, essential in gaining the confidence of the regulatory permitting agencies;
- The PDT could develop and sequence phases of the project so that they were compatible with staging sequences with adjacent SFOBB dismantling projects; and

- The Department could reduce risk and avoid delays that typically had occurred for many complex projects in the Toll Bridge Program.

2.3.2. CMGC Selection Process

The Department received Statements of Qualifications from six contractors, and on August 26, 2014, signed a contract with the Kiewit-Manson Joint Venture (K-M) with Contract Drilling and Blasting LLC (CDB) as their blasting subcontractor.

2.3.3. CMGC Preconstruction Services Phase

The Department began design of the Marine Foundations removal in September 2014, and the PDT decided to divide the contract into three distinct projects for several reasons. The Marine Foundation removal contracts needed to be aligned with milestone dates for the release of foundations from the superstructure dismantling contract. Priority was placed on maximizing the probability of successfully obtaining permits for the complete removal of Pier E3 by August 2015. The PDT also recognized that the TBPOC desired retention of Pier E2 and Piers E19 to E22 to create public access at both shorelines near the new SFOBB East Spans. The three projects included:

- Pier E3 Demonstration Project (04-013544)
- Pier E4 to Pier E18 Marine Foundation Removal Project (04-013574)
- Pier E2 and Piers E19–E22 Pier Retention Project (04-013584)

2.3.4. CMGC Pier E3 Demonstration Project

The PDT began to develop the required analysis of all alternatives contemplated to assess potential impacts on the Bay environment that would be created by the means and methods in each alternative. The use of controlled charges was determined to create the least potential impact, and the PDT moved forward with development of a 100% design using this method as the primary removal method for all the piers. The Department and K-M agreed to a GMP in March 2015, and a construction contract was awarded on April 17, 2015. The mechanical dismantling operation for Pier E3 began on June 1, 2015, and the pier was imploded successfully on November 14, 2015.

2.3.5. CMGC Pier E4 to E18 Foundation Removal Project

With the successful implosion of Pier E3, the Department could move forward and negotiate a contract with K-M for removal of Piers E4 to E18. This project was divided into three phases, primarily because of scheduling considerations for the release of foundations from the 504/288 Dismantling Contract. The three project phases include:

- 2016 Phase 1-Pier E4 and E5 Removal

- 2017 Phase 2- Pier E6 through Pier E11 Removal
- 2018 Phase 3-Pier E12 through Pier E18 Removal

The Department and contractor agreed on a GMP in March 2016, and a construction contract was awarded on April 9, 2016.

2.4. Blast Plan Design

2.4.1. Blast Plan Design Basics

Many factors must be considered when designing the blast of a structure. Blast design requires qualified and licensed personnel, experienced in the science of using explosive material to break concrete. Basic physical parameters that include hole diameter and spacing, hole depth, type and weight of explosive material, and the initiation system are all designed to optimize fragmentation size and achieve the desired results with respect to complete collapse of the structural elements.

2.4.2. Designs for Pier E3 to Pier E5 Caisson Removal

The blast plans developed for removal of Piers E3 to E5 during the Pier E3 Demonstration Project and the 2016 Phase 1 Removal Project each contained the following design considerations:

- Safety of personnel involved with blast day operations;
- The condition of the existing pier, including, but not limited to, concrete strength, location of reinforcing steel and splices, and location of utilities and materials used to construct the pier;
- The proximity to the new SFOBB East Spans;
- The proximity to existing utilities, such as the BART Transbay Tube and the EBMUD sewer outfall pipe;
- Limits of removal and the water depths at each pier;
- Intrusion of water into drilled holes and wet hole mitigation; and
- Environmental restrictions and protection of marine life in the immediate blast area.

Piers E3, E4, and E5 are all deep-water caissons, each with a cellular structure that extends over 150 feet below sea level. The blast plans were designed to break the reinforced concrete structures into small enough pieces so that the majority of the concrete would fall into the caisson cells below the mudline of the Bay. Concrete rubble that was thrown outside the footprint of the caisson and clearly above the specified removal limits was collected with a clamshell operation and moved into the footprint. Pre- and post-blast sonar surveys (discussed further in Chapter 7) were used to verify compliance with contract documents and specified removal limits.

Each blast design consisted of drilled holes that were completed to specified depths corresponding to the required removal limits. The size and spacing of boreholes were designed for maximum fragmentation and transfer of energy to the concrete being broken. The interior walls of the caisson foundations were drilled to depths 20 feet deeper than the exterior walls, to create more space in the interior of the caisson into which the blasted concrete would fall. The typical blast column layout is shown in Figure 2-1. To minimize bore hole deviation during the vertical drilling operation to depths of more than 70 feet, a specialized drill string configuration was used. In addition, all drilling equipment was equipped with electronic inclinometers to confirm and control the vertical alignment of the drill boom.

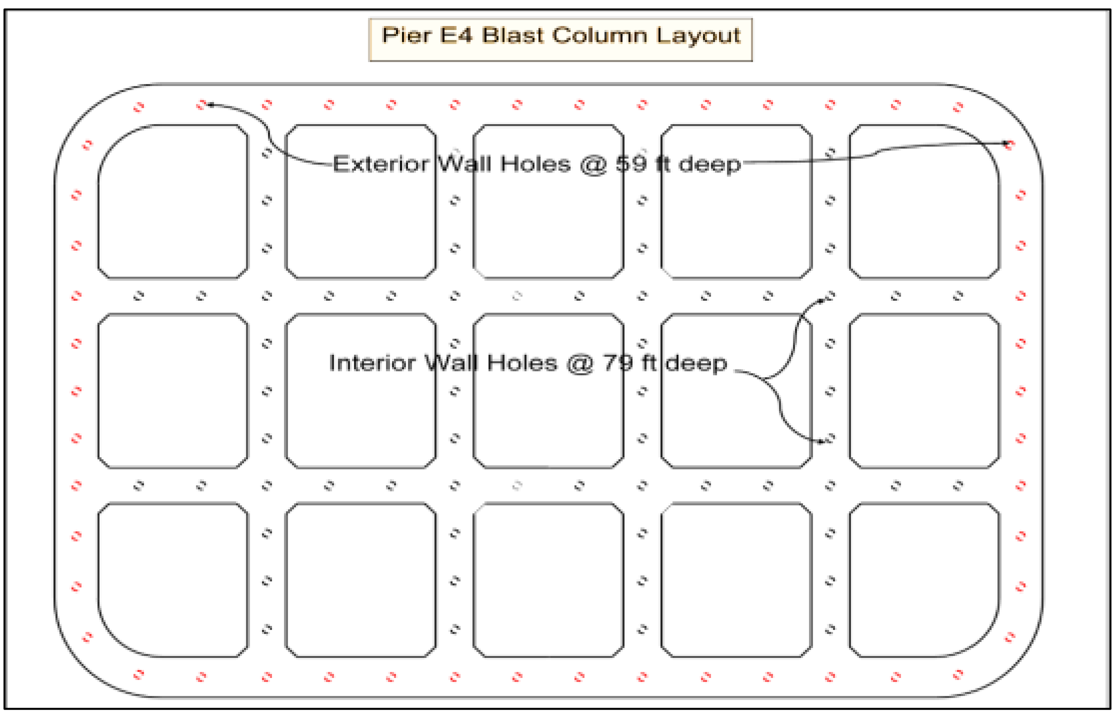


Figure 2-1. Typical Blast Column Layout (Pier E4 Shown)

The blast column layout in each borehole consisted of decks of explosive material with two electronic detonators in each deck, for redundancy and to ensure detonation. Electronic detonators have the added benefits of allowing the accurate programming of firing times and providing feedback to the programmer that they are "ready." The explosive decks were separated by stemming material of angular crushed gravel, confining the explosive energy in each deck and preventing premature escape of gases created during the detonation. A typical blast column loading is shown in Figure 2-2.

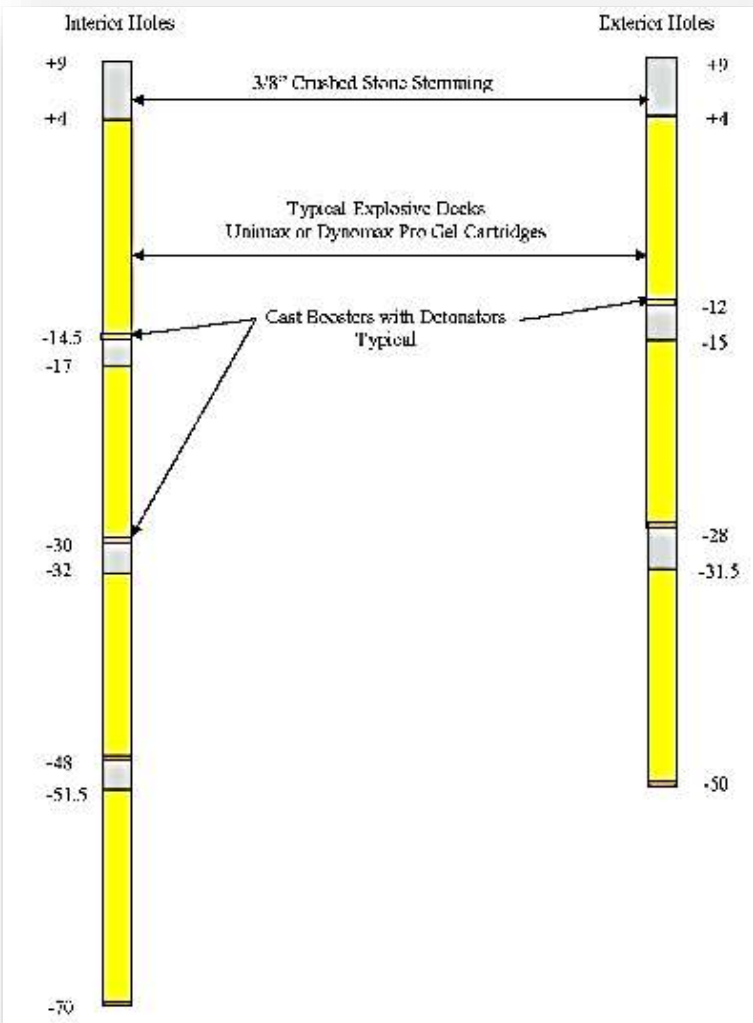


Figure 2-2. Typical Blast Column Loading (Pier E4 Shown)

During the drilling operation for Pier E3, water was encountered in over 25 percent of the drilled holes. Water intrusion into blast columns is a concern because it can have adverse effects, resulting in a less than desirable blast. The blasting contractor recommended the following changes to the original blast design, to address concerns and mitigate the wet hole conditions:

- Cast Boosters were used to house the blast caps and initiate detonation. This change eliminated the need to puncture the explosive cartridges in each deck to maintain their integrity.

- The stemming and cartridge were placed in poly liners (waterproof membranes).

- Wet holes were loaded last to minimize the time that the explosives were exposed to water.

- Explosives were loaded in double shifts to minimize the time of exposure.

2.4.3. Blasting Sequences and Procedures

The blaster-in-charge also was responsible for outlining (designing) the sequences and procedures for each blast, for the safety of all personnel involved. Following mechanical removal of concrete above the pier cap (Figure 2-3) and after the drilling of holes was completed (Figure 2-4), the blast columns were ready for loading. The explosive material was transported to the project site in accordance with all applicable regulations and permits required for the project. The project site and each individual pier were secured as required throughout this process. On completion of the loading of charges, the initiation circuit from hole to hole was completed and tested to ensure that all holes would fire in accordance with the designed sequence. Blast mats were secured to ensure that fly rock would be minimized. All loading operations were planned and completed to allow the blast event to occur at high slack tide, so that the water currents were at a minimum and to optimize the effectiveness of the BAS.

Figure 2-3. Mechanical Removal of Concrete Above Pier Cap (Pier E3 Shown)

Figure 2-4. Blast Holes Drilled and Readied for Loading (Pier E3 Shown)

Each blast event began with a safety briefing for all personnel involved with the operation. Environmental monitors were deployed several hours before each blast, to ensure compliance with all applicable permits. Hydroacoustic monitoring equipment and the BAS were readied and initiated. After these operations were completed and all personnel were in place, the marine blast safety zone of 1,500 feet was secured by the CHP and was controlled throughout the event. After the blaster-in-charge received input from the environmental monitors that no marine mammals or listed bird species were in the exclusion zones, traffic on the new SFOBB East Spans was brought to a rolling stop in both directions of travel. Warning signals were sounded and an air cannon was fired to vacate any birds present before the shot. After the blast was detonated, the blaster-in-charge completed a visual check of post-blast conditions that included waiting for the dissipation of any smoke or hazards created by the blast before signaling an “all clear” in the blast zone. After the “all clear” was given, traffic was allowed to resume and project personnel were allowed to enter the blast zone to complete post-blast activities. For the safety of all personnel, the CHP retained control of marine traffic until post-blast activities were completed.

2.4.4. Contingency Plan

Blast misfires were highly unlikely because of the type and redundancy of detonators being used. In addition, the blaster was able to identify non-responsive or damaged detonators before each blast event, through computer verification of signals. Regardless of these measures, each blast plan had a contingency plan for misfires, with specific procedures to be followed in the event of a misfire. The secure 500-foot danger zone was to be maintained while the blaster conducted an investigation to determine the cause of the misfire and appropriate steps were to be taken to correct the condition. The Project Manager was to be advised of the correct procedure to be implemented.

2.4.5. Control of Water Overpressure

Each blast was designed to minimize overpressure produced in the water column surrounding each pier. Controlling the weight of explosive material detonating at any one time (pounds per delay), the use of programmable electronic detonators to ensure precise firing times of each explosive deck as designed, and the use of the BAS were measures taken to address this issue. Confinement of explosives in the concrete and adequate stemming lengths in the blast columns also helped to reduce overpressures created by the blast.

2.4.6. Chemical Reaction and Blast Byproducts

Blasting operations produce both toxic and nontoxic gaseous byproducts. The yellow/orange colored smoke produced during each implosion is a combination of carbon monoxide and various nitric oxides, and they are well-defined byproducts of any explosion (which basically is a chemical reaction). All blasts are designed to have as complete combustion of the explosive material as possible. The wet hole mitigation procedures (as discussed in Section 2.5.2) reduced the amount of toxic gases produced as a byproduct of the lack of combustion of explosive materials. These gases are more of a concern for workers or public safety when blasting in confined spaces (such as mines or underground in quarries), where gases can accumulate in soil and collect in confined spaces, and when blasting high volumes of explosives (millions of pounds versus thousands). In addition to the mitigation measures discussed to minimize the quantity of toxic fumes produced, the blaster-in-charge used the following procedures to ensure the safety of workers and the public:

- Placing workers and support barges out of the direct path of fumes; and

- Waiting for these gases to dissipate and dilution with air to occur before giving the “all clear” for any workers to enter the work zone to begin debris collection after each event.

2.5. Blast Design Parameters

Table 2-2 shows the preliminary blast designs developed by CBD for Piers E4 through E18.

Based on the successful implosion of Piers E3, E4, and E5 as well as lessons learned during each implosion operation, the CMGC team began investigating the feasibility of reducing the total number of blast events. The Department recognized that this would reduce the total number of blast seasons from three to two, decrease the cumulative risks to workers and the public, and help to reduce overall project costs. Potential impacts created by imploding multiple foundations in one event, with each foundation implosion being separated by a delay time to squelch the additive effect of pressure waves, are being evaluated.

Table 2.3 shows that the combination of the various parameters for each proposed multiple foundation event would result in less total explosive weights and blast durations than the three successful implosion events. The maximum charge weight per delay also would be reduced. The CMGC team is confident that the blast events outlined above could be designed and implemented during the 2017 blast season. A graphic representation of the combined values of each category for these events is shown in Figures 2-5, 2-6, and 2-7.

Table 2-2. Blast Design Parameters

Pier	Individual Charges Per Pier (each)	Total Explosive Weight (pounds)	Approx. Total Blast Duration (second)	Maximum Single Charge Weight (pounds)	Pier Concrete Volume (cubic yards)
E3	588	16,876	5.300	35	7,335
E4	406	11,850	3.564	35	5,920
E5	288	8,128	2.592	35	4,390
E6	636	15,380	5.724	32	6,045
E7	324	6,480	2.916	25	2,680
E8	104	2,080	0.936	25	1,425
E9	282	5,640	2.538	25	3,500
E10	96	1,920	0.864	25	1,100
E11	96	1,920	0.864	25	1,170
E12	96	1,920	0.864	25	1,030
E13	96	1920	0.864	25	1,030
E14	96	1920	0.864	25	1,030
E15	96	1920	0.864	25	1,000
E16	96	1920	0.864	25	1,000
E17	102	2040	0.918	25	1,200
E18	102	2040	0.918	25	1,200

Table 2-3. Modified Blast Design Parameters for Multiple Foundation Implosions

	Pier(s) in Implosion Event	Total Individual Charges per Implosion Event	Total Explosive Weight per Implosion Event (pounds)	Approx. Total Blast Duration per Implosion Event (seconds)	Maximum Single Charge Weight (pounds)	Total Pier Concrete Volume per Implosion Event (cubic yards)
Successfully Completed Pier Implosions	E3	588	16,876	5.300	35	7,335
	E4	406	11,850	3.564	35	5,920
	E5	288	8,128	2.592	35	4,390
Planned Implosions	E6	636	15,380	5.724	32	6,045
	E9	282	5,640	2.538	25	3,500
Proposed Multi-Pier Implosions	E7 and E8	428	8,560	2.916	25	4,105
	E10 and E11	192	3,840	2.728	25	2,270
	E12 and E13	192	3,840	2.728	25	2,060
	E14 and E15	192	3,840	2.728	25	2,030
	E16, E17, and E18	300	6,000	4.700	25	3,400

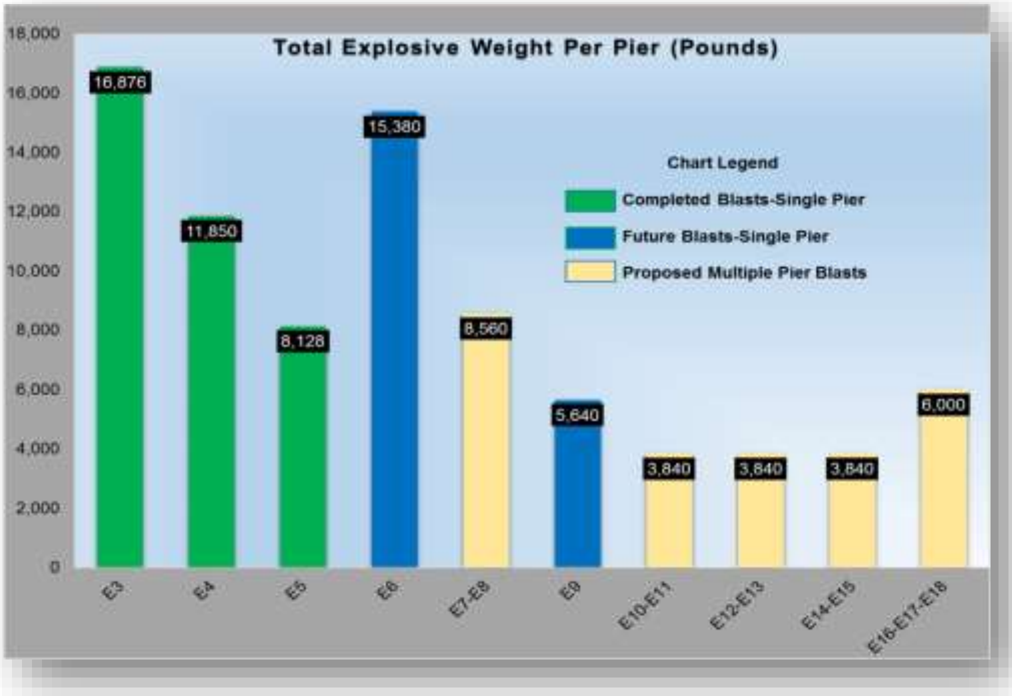


Figure 2-5. Comparison of Explosive Weights

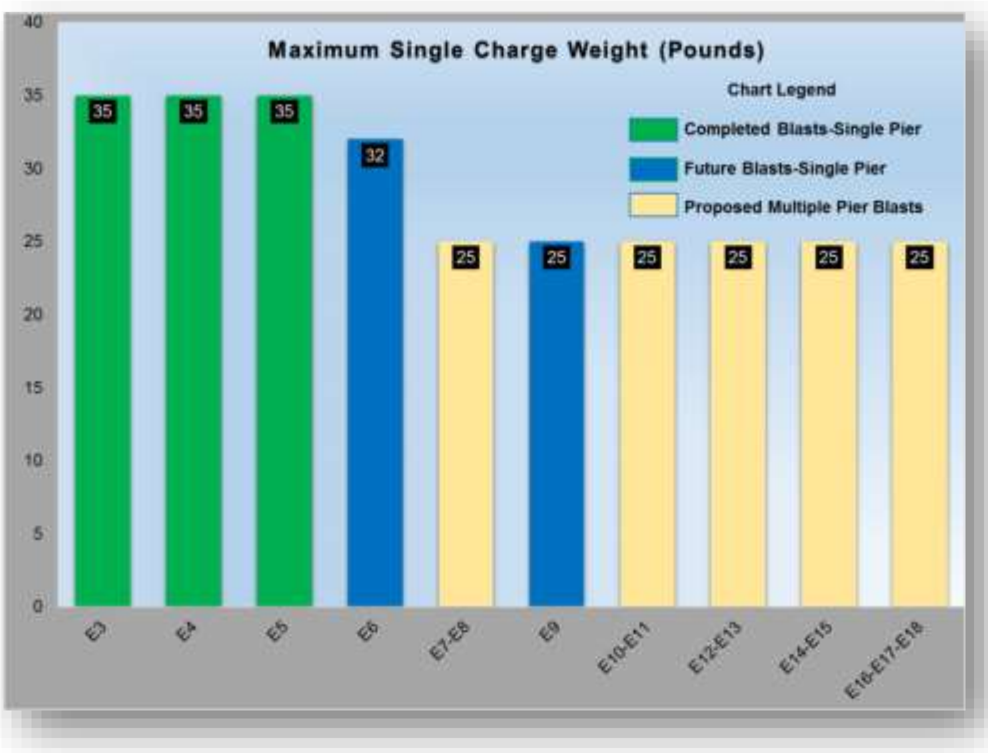


Figure 2-6. Comparison of Maximum Single Charge Weights

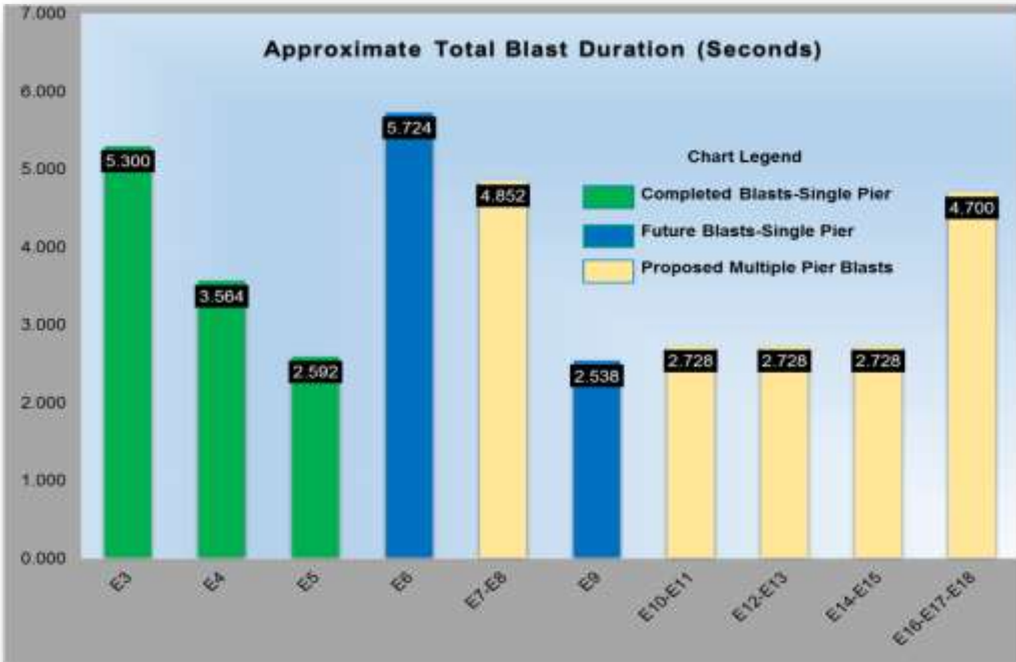


Figure 2-7. Comparison of Approximate Total Blast Durations

2.6. Conclusions

- Based on the successful implosion of Piers E3, E4, and E5, the remaining marine foundations of the old SFOBB can be removed safely and with minimal impacts on the Bay environment using controlled blasting methods.
- The CHP maintained safe and effective control of marine traffic before, during, and after the blast event.
- Based on the successes achieved through the CMGC program, the PDT can design and schedule the removal of the remaining marine foundations with an emphasis on a reduction of the total number of blast events and can facilitate an earlier than originally scheduled completion date for the project.
- The total number of blast events could be reduced from 13 blast events of individual foundations over two blast seasons, to as few as seven blast events of multiple foundations conducted in one season.
- Yellow/orange smoke, which occurred during the Piers E3, E4, and E5 implosions, is expected to occur during all future blast events.

Chapter 3. Blast Attenuation System Design and Efficiency

This chapter outlines the successful design, testing, deployment, and operation during the demolition of Piers E3, E4, and E5. The BAS was a key element to the successful demolition of these piers, and in particular, the protection of fish and marine mammals outside the BAS perimeter.

3.1. Regulatory Guidance

Regulatory guidance for the BAS, in terms of overpressure and its energy, was provided by the National Marine Fisheries Service (NMFS) and CDFW. The guidance is analogous to measures of sound in air, which were developed for human hearing testing, monitoring, and safety. Overpressure is the temporary oscillation of any source from the static pressure level in water because of the depth below the water surface. For implosions, like the SFOBB pier removals, the source produces a wave that lasts just longer than the length of all the separate delay charges being detonated in the shot pattern. The overpressure wave lengthens in duration with increasing travel distance from the source.

Two measures of overpressure are related to the amplitude, or loudness, of the waveform resulting from the causative source: the maximum amplitude of the wave, which is termed either the peak overpressure or the sound pressure level (SPL); or the root mean square (RMS) overpressure level, often shortened to RMS level. The amplitude of the overpressure is similar to the variable loudness of sound with the volume control of a radio or television. The peak overpressure is measured in units of pressure—pounds per square inch (psi)—the same unit as the air pressure of car tires. SPL, which is equivalent to peak overpressure, is measured in logarithmic decibels (dB) of pressure (dBp), because of the large range of peak overpressure amplitudes. Peak overpressure for human hearing in air may be: 60 dBp SPL for normal conversation, 110 dBp SPL at 3 feet from a chainsaw, 120 dBp SPL for uncomfortable noise, and 140 dBp SPL at 160 feet behind a jet aircraft's engine. The RMS level also is measured in dBp but requires more analysis of the overpressure wave than merely finding the maximum amplitude. The RMS level should be considered as a time averaging of the overpressure amplitude.

The metric of overpressure energy that is used as guidance is the sound exposure level (SEL). SEL is a useful computation of energy resulting from the overpressure at a given distance from the source, because it allows comparisons in a single value of the energy received from sources of different amplitudes and durations. SEL allows comparison of the energy received in water between these SFOBB pier removals to another site where pile driving was conducted for days in a river. As an example for human hearing in air, SEL could note the energy received by an individual's ears during 3 hours use of a chainsaw versus the short exposure of being behind a jet aircraft moving away from a person at the nearest distance of 200 feet. SEL is measured in logarithmic decibels of energy (dBe). (The decibels of overpressure amplitude, dBp, are not related to the decibels of overpressure energy, dBe. The two units of decibels are merely logarithmic values.)

The development of appropriate marine blasting guidelines is challenging. As noted by Popper et al. (2014), "The problem for setting guidelines is that the studies [that] have examined the effects of explosions on fishes have each used different species, different types of explosives, and/or charges of different weights …. No data on the effects of explosions on hearing or behavior are available." Popper, et al. only used peak overpressure as guidelines for explosives; no overpressure energy measure is provided as a guideline.

3.2. Design of the BAS

3.2.1. General Constraints for the Design

As recognized early on, removal of the two largest piers, E3 and E4, placed several adversely competing constraints on the BAS design. The system had to make up a large enough perimeter to surround Piers E3 and E4, while also having sufficient distance from the piers that falling debris would not damage the aeration frames of the BAS for future use on later pier removals. The BAS had to be operated without any land-based support. The system required redundancy, so that a failed aeration line would not leave a gap in the protected perimeter. The BAS needed to achieve the largest reduction of marine organism impacts and peak overpressure that could reasonably be fielded by a contractor.

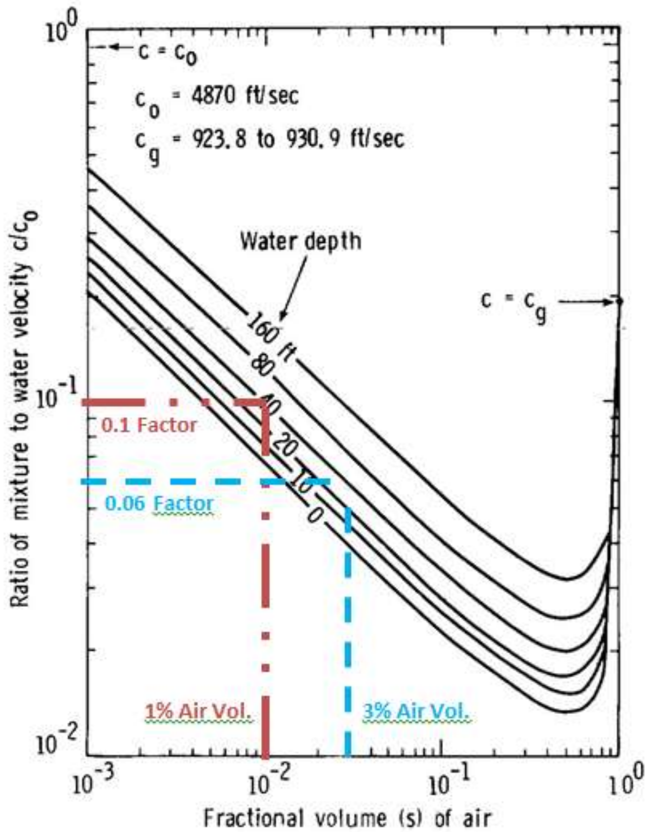
3.2.2. BAS Design Development

The BAS consists of a curtain of bubbles rising from aeration frames, lying on the floor of the Bay and surrounding the bridge pier. Properly designed, the BAS substantially modifies the water-borne pressure waveform passing from an explosive source through the curtain of bubbles and to the ambient water column beyond the curtain. With sufficient air volume uniformly dispersed from the bottom of the water column, the rising bubbles of the BAS reflect, refract, and attenuate the pressure wave caused by the explosive source. The BAS changes the physical waveform by reducing the pressure amplitude, lowering the frequency content, and lengthening the duration of the blast pattern wave.

During the APS, these general constraints were considered for creating a conceptual BAS design. The awarded contractor then would progress from the conceptual BAS design to development of a final design, which would be verified to meet specified requirements. The contractor would be required to provide: a finalized aeration frame design; calculations of the air-fraction to water volume above the frame; a field test of two frames before construction of all the aeration frames; and finally, deployment and a full test of the BAS surrounding Pier E3 with sufficient time before the demonstration demolition to make any needed revisions.

The BAS changes the physical waveform by reducing the pressure amplitude, lowering the frequency content, and lengthening the duration of the input wave as the pressure wave passes through the curtain of air bubbles (Hempen, 1993). The function of the air bubble, which is much, much more compressible than is water, is to increase the compressibility, or to lower the bulk modulus of the bubble zone. Theoretically, if the modulus at the bubble zone is reduced to a zero value (for example, corresponding to 100 percent air), then the bubble curtain will provide a perfect shielding effect to prevent any water pressure from propagating outside the curtain for any amplitude of the blast wave inside the curtain, and hence creating zero fish damage. However, practical reasons limit the contractor to being able to generate only a small proportion of air bubbles—on the order of only a few percent by volume. Figure 3-1 shows a theoretical solution of the relationship of the bulk modulus (which is related to the wave propagation speed) at the bubble zone as a function of the proportion of air by volume within the bubble zone. The horizontal axis in the figure denotes the fractional volume of air and the vertical axis shows the ratio to be applied to the wave speed of pure water for the propagation speed of the bubble zone. The bulk modulus, which directly affects the amplitude of the pressure in the bubble zone, is proportional to the square of the wave speed.

In Figure 3-1, the effects of a 3 percent and a 1 percent air volume are noted and the theoretical solutions showed that they correspond to a 0.06 and a 0.1 factor on the wave speed values. These wave speed factors correspond respectively to a 0.0036 and a 0.01 factor to the bulk modulus, which can imply a corresponding change in the pressure amplitude. An appreciation of this issue, that just a small percentage of air (what can be achieved practically in the field by the contractor), provides the best technical basis to justify the expense for the provision of the BAS (which is not an inexpensive item) in the demolition contract.



Note: Ratio of velocity c in an air-bubble/water mixture to velocity c_o in a bubble-free water versus fractional volume s of air in the mixture, for ambient pressures P_a corresponding to water depths shown.

Source: Domenico 1982

Figure 3-1. Relationship of Bulk Modulus and Fractional Volume of Air

Thus, to be effective, the BAS only needs to achieve a minimum 3 percent air-fraction to water volume in the water column. With a 3 percent air-fraction, a substantial reduction in the physical parameters of the water-borne waveforms passing through the BAS can be achieved and cause other emanating waves to be diffracted though Bay sediment beneath the BAS. Meeting the minimum 3 percent air-fraction requires many large air compressors on barges near the BAS to supply the necessary air volume. A minimum air fraction greater than 3 percent possibly would require more large air compressors than could be available. With a 3 percent air-fraction, the number of air compressors required would be able to be obtained, with sufficient planning and lead time.

For the APS, EMI designed a system of identical aeration frames to accept standard fittings for a 3-inch hose delivery from the air compressors. To assure a redundant system, three aeration lines are in each aeration frame. A copy of the conceptual BAS design, as presented in the APS, is provided in Appendix A.

3.2.3. BAS Design Goals Met

K-M developed its own design of the BAS to be used for each of the first three pier demolitions. Although elements of its design are proprietary, much of the aeration frame design was substantially equivalent to the conceptual design presented in the APS. K-M provided mechanical engineering calculations to show the minimum 3 percent air-fraction to water volume to be obtained above the frame. Both the field test of two frames before the remaining aeration frames were built and a full test of the fielded BAS surrounding Pier E3 was conducted satisfactorily. No need occurred to make any revisions to the K-M-fielded BAS, as it performed well in pre-demolition tests.

3.3. BAS in service for Piers E3, E4, and E5

After the explosives are fully loaded and the pattern was completely wired, limited time remained until the shot had to be fired. The fully operational BAS was only one of several required components to initiate the piers' demolitions. The BAS was operating properly before firing the demolition shots. An artist's rendering of the BAS setup at Pier E3 is shown in Figure 3-2 and an aeration frame is shown in Figure 3-3.

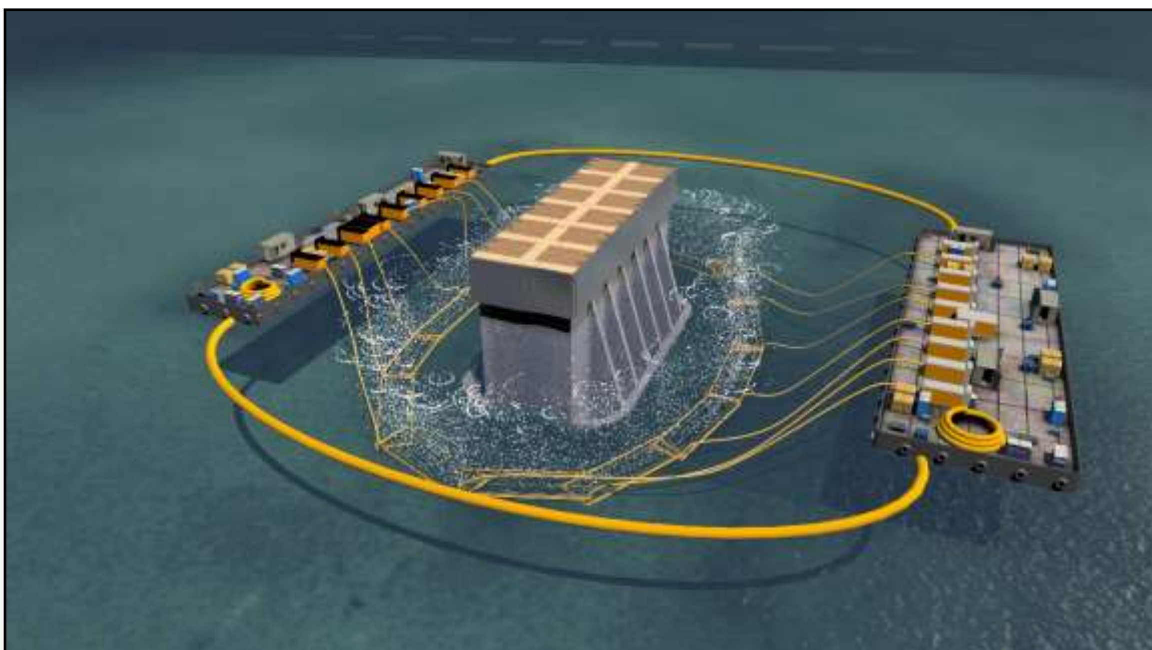


Figure 3-2. BAS Setup for the Pier E3 Demolition

Figure 3-3. BAS Aeration Frame

3.4. Verifying BAS Efficiency, Physical Parameters

A direct property, which has been cited in the literature for underwater natural resources impacts, is peak overpressure (also referred to as peak pressure) of the entire waveform. The peak overpressure may be measured in specific locations by either pressure transducer systems or hydrophone systems in pressure units of psi or in SPL units of dBp. The efficiency of the BAS was determined using the comparison of peak overpressures measured inside and outside the BAS. To facilitate the determination of BAS efficiency as well as to understand pressure decay with distance from the pier, a number of pressure transducers were suspended in water at a depth of about 20 feet. For the Pier E3 blast, the pressure monitoring program included both near-field and far-field pressure monitoring at locations ranging from 25 to 4,000 feet from the pier.

Figure 3-4 shows the measured peak overpressures plotted against scaled distance for the South Recording Array of Pier E4's implosion, where the Caged Fish Study was located. The scaled distance is the distance divided by the cubic root of the weight of the explosive per delay, which is a customary way to express in the blasting industry, based on the Hopkinson-Cranz cube root scaling law. The law shows that blast effects from different sizes of explosives are similar at the same scaled distances.

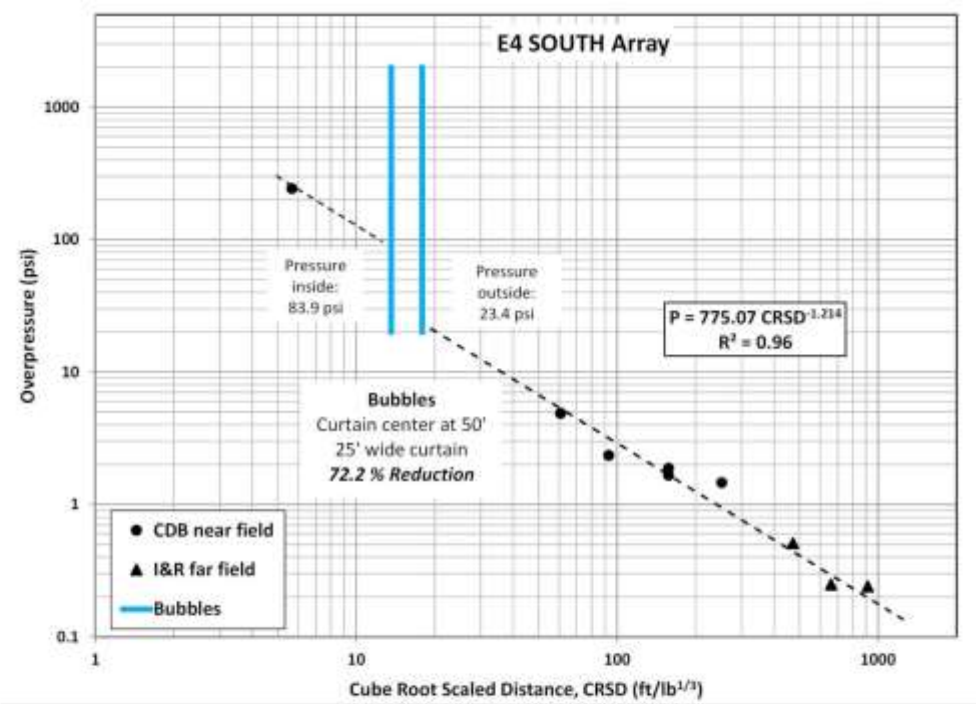


Figure 3-4. Peak Overpressure Inside and Outside the BAS for the Pier E4 Blast, South Recording Array along the Caged Fish Study

Three recording arrays occurred for the Piers E3, E4, and E5 implosions. The Caged Fish Study was conducted along the South Recording Array for each implosion. The best fitted relationship is shown with dashed lines in the Figure 3-4; the location of the BAS is indicated with two vertical blue lines. By comparing the peak overpressures inside (83.9 psi) and outside (23.4 psi) of the BAS, the efficiency is estimated to be 72.2 percent for Pier E4's South Array, as shown in Figure 3-4. For the recorded arrays of blasts from Piers E3, E4, and E5, the peak overpressure reduction efficiency for the BAS was averaged to be 73.6 percent, ranging from a low value of 70.6 percent to a high of 79.7 percent. Figure 3-5 shows all peak overpressure data collected and plotted together for the blasting of three piers to illustrate the general trend of pressure decay.

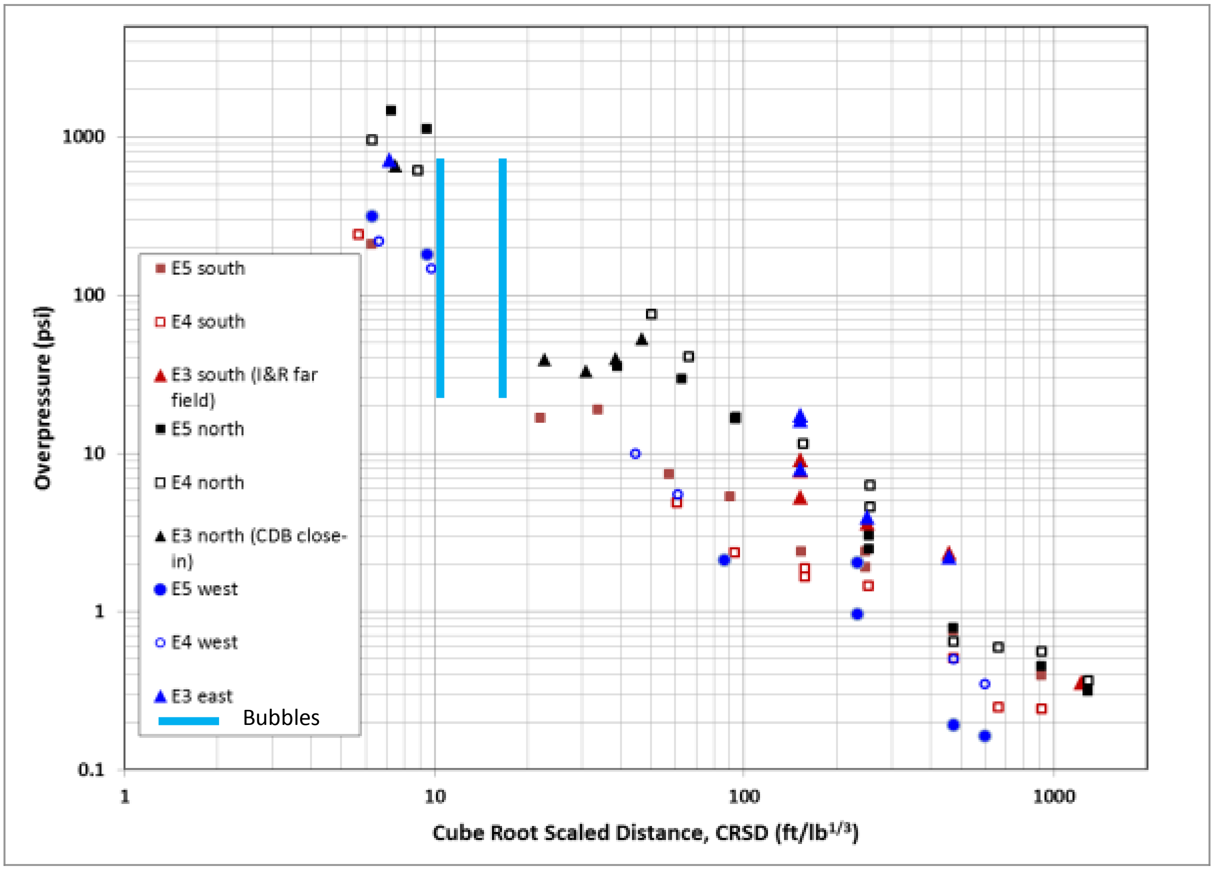


Figure 3-5. Peak Overpressure Data for the Blasts of Piers E3, E4, and E5

The area subjected to the CDFW Exposure Level of 2.9 psi peak overpressure (206 dBp SPL) or greater is reduced substantially solely by the operating BAS. The peak overpressure along the South Recording Array (the line of the Caged Fish Study) of the Pier E4 implosion did not dissipate to 2.9 psi until 255 feet from Pier E4. The distance to 2.9 psi peak overpressure without the BAS operating may be approximated by a standard comparison to the peak overpressure recorded within the BAS. The distance estimation of 2.9 psi peak overpressure from the interior recording of the BAS (243 psi at 18 feet) for the Pier E4 South Array, as if the BAS was not operating, occurs at 910 feet from Pier E4. This reduction for the Pier E4 South Array is an area reduction of 92 percent for the CDFW exposure level with the BAS in operation. The efficiency of the BAS in reducing the area exceeding 2.9 psi (206 dBp) exposure level is averaged as 90.7 percent for the six recording arrays of the Pier E4 and E5 implosions.

3.5. Fish Mortality Studies Verifying the BAS Efficiency

The demonstrated effectiveness of a BAS relies on its ability to dramatically modify a pressure waveform. However, relying solely on reductions in pressures to assess the effectiveness of the BAS does not tell the whole story. **Fish mortality testing provides a confirmation of BAS effectiveness based on a biological endpoint, live or dead**. Data were collected during the Pier E3 demolition, but the test fish were in poor condition, suffering excessive net pen mortality and control mortality. Lessons learned (e.g., transitioning fish from freshwater to saltwater, holding, general study design, necropsy team protocols) from the Pier E3 demolition were used to better conduct Pier E4 and E5 studies.

Four cages, each containing 25 Chinook salmon, were suspended from ropes designed to hold cages at a depth of 15 feet at each test distance (i.e., 120, 200, 500, and 800 feet) from the pier on the protected side of the bubble curtain (Figures 3-6 and 3-7).

In addition, 25 fish each were placed into four control cages. Control cages were handled and deployed in the same manner as the experimental cages, but with a few exceptions. The experimental fish at the 120-foot distance from the pier also were exposed to the strong currents and bubbles produced by the BAS, which were not experienced by the other cages or the controls.

Percent mortality of Chinook salmon from the Pier E4 and E5 implosions is shown in Table 3-1 and Figure 3-8. For Pier E4, only one fish exposed to the detonation blasts, located 200 feet from the pier on the protective side of the BAS, was classified as dead based on necropsy. For Pier E5, only one caged fish, located 500 feet from the pier, and one net pen control fish were classified as dead based on necropsies. **Only two of the 801 fish exposed to the Pier E4 and E5 blasts while protected by the operating BAS had injuries that could be attributed to barotrauma.**

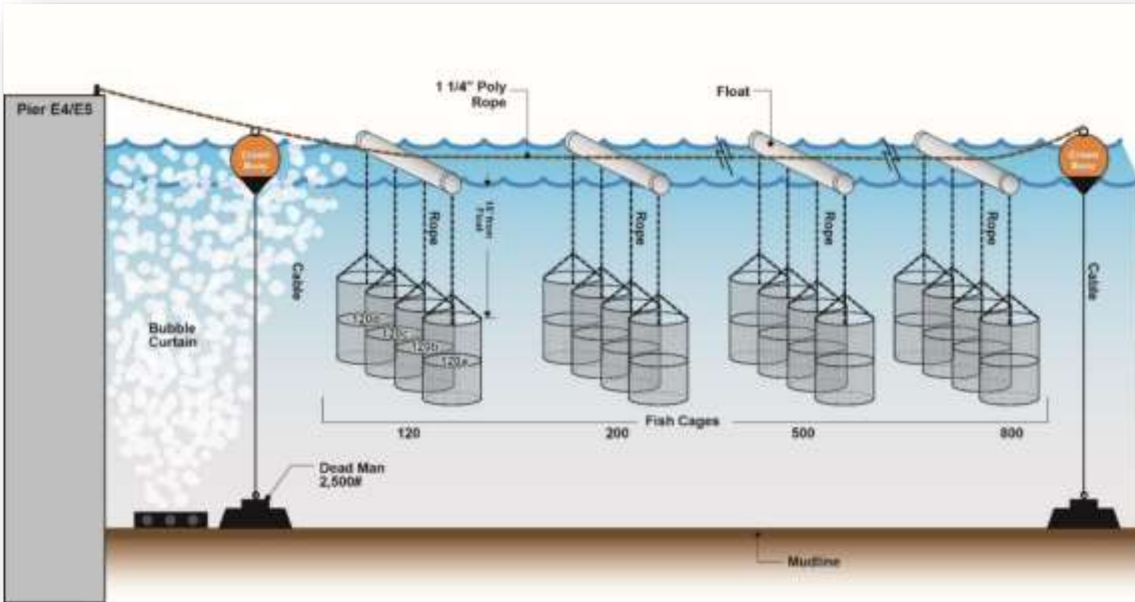


Figure 3-6. Cage Positions Relative to Piers E4/E5 and the BAS (Bubble Curtain)

Figure 3-7. Deploying Fish Cage at Pier E4

Table 3-1. Percent Juvenile Chinook Salmon Mortality Scored by Necropsy and Mortality

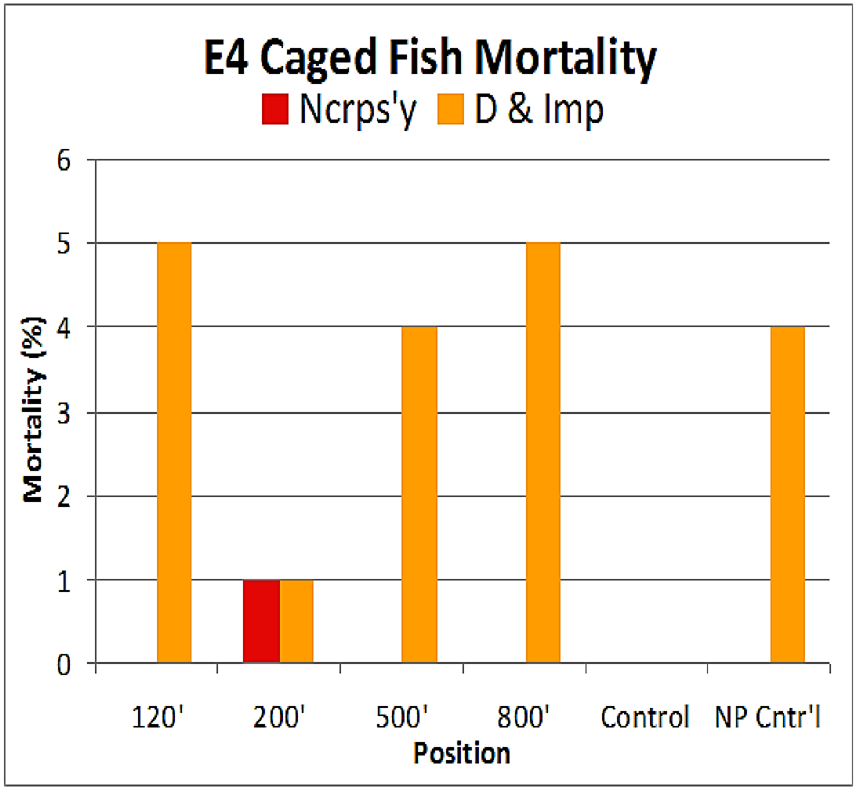
Position from Piers E4 and E5	E4 Demolition		E5 Demolition	
	Necropsy Mortality (%)	Dead and Impaired (%)	Necropsy Mortality (%)	Dead and Impaired (%)
120 feet	0	5	0	5
200 feet	1	1	0	4
500 feet	0	4	1	4
800 feet	0	5	0	2
Caging and Deployment Control	0	0	0	1
Net Pen Control	0	4	0	0

Note:
Based on post-exposure assessment of immediate mortality and impaired swimming at 120, 200, 500, and 800 feet from Piers E4 and E5 and two controls, caging and deployment control and net pet control (net pen holding only).

No substantial difference occurred in the incidence of mortal injuries between any of the cages deployed off Pier E4 or E5 and their respective control cages. No blast-related mortality or injury at any distance is likely. Mortality determined by necropsy is considered to be the most reliable measure of blast pressure-related fish mortality (Gaspin et al. 1976; Wiley et al. 1981) and is the standard technique to assess barotrauma-related blast mortality.

In addition to the mortality based on internal injury scores determined by necropsy, fish also were classified as dead if they were found dead in their cage or found to have impaired swimming abilities (e.g., swimming on their sides, swimming in circles) immediately after the detonation. Fish with impaired swimming would be susceptible to predators and would not be expected to survive. Fish that showed immediate mortality or impaired swimming also were necropsied, and only one fish was found to have internal injury. For Pier E4, 15 experimental fish and two net pen control fish were classified as immediately dead or impaired. For Pier E5, 15 experimental fish and one control fish were classified as immediately dead or impaired.

For the Pier E4 and E5 blasts, exposed fish mortalities were not substantially different from control mortality based on the total dead plus impaired count. Many of the fish found dead or with impaired swimming immediately after the blast had no barotrauma-related internal injuries. Quite possibly these fish were killed by factors other than the blast, such as handling.



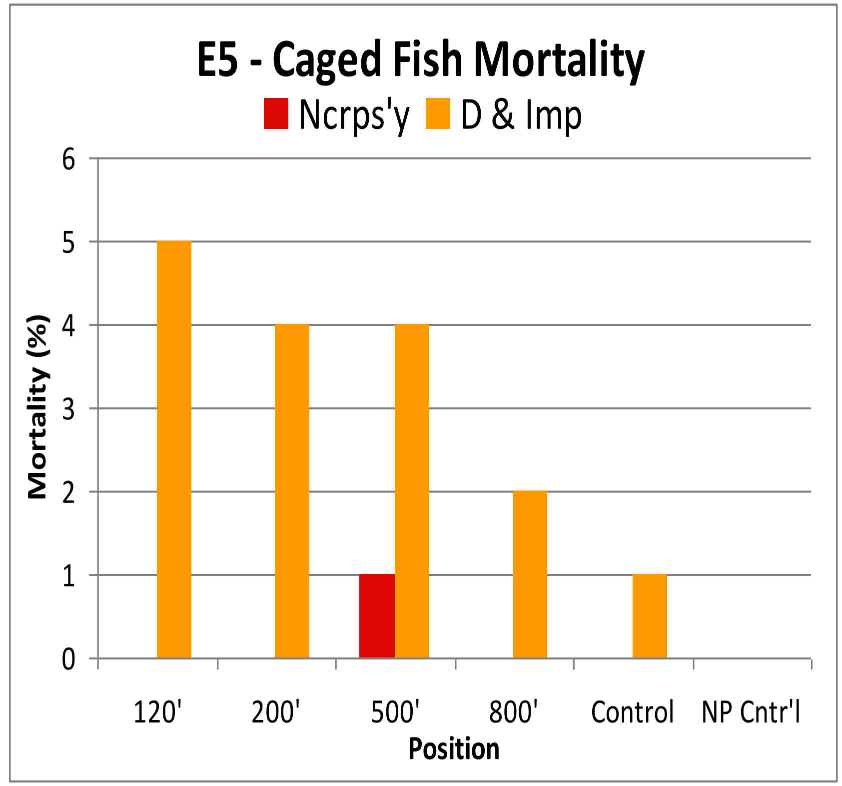


Figure 3-8. Caged Fish and Controls Mortality, Piers E4 and E5 Demolition

To most precisely determine the effectiveness of the BAS, it is necessary to compare fish mortality with the BAS in operation to the no BAS operation condition. However, resource agencies would not approve pier demolition without an operating BAS, so an alternative approach is to compare mortality data with the operating BAS with existing injury/mortality criteria (peak pressure level at which injury or mortality first occur), based on pressure recording. A 2.9 psi (206 dBp) peak pressure criterion (a pressure guideline not to be exceeded), developed by the Fisheries Hydroacoustic Working Group (FHWG) for pile driving (FHWG 2008), was the CDFW guidance for this project. For Pier E4 without the BAS in operation, 2.9 psi occurred to approximately 910 feet, based on extrapolated pressures from data collected inside the BAS. With the BAS in operation, 2.9 psi occurred to approximately 255 feet, or a reduction of 655 feet. For Pier E5, 2.9 psi occurred to approximately 420 feet with the BAS operating and 890 feet without, for a reduction of 470 feet.

Essentially no mortality occurred at any distances tested for both Pier E4 (120 feet, 8.7 psi, and 200 feet, 4.7 psi) and Pier E5 (120 feet, 16.5 psi, and 200 feet, 6.5 psi) for areas within the 2.9 psi radius with the BAS in operation. Based on the lack of evidence of blast pressure-related barotrauma in the test fish, the 2.9 psi peak overpressure regulatory criterion appears to be excessively conservative for exposure to confined or partially confined underwater blasts.

3.6. Operational BAS, Conclusions

The BAS is very efficient in reducing peak overwater pressure, as indicated by the pressure monitoring programs. The BAS greatly reduces the area exceeding 2.9 psi peak overpressure (206 dBp SPL) exposure level guidance from CDFW. Direct evidence of the effectiveness of the BAS can be found from the caged fish study programs. Salmon mortality was extremely low for the Pier E4 and E5 demolitions with the BAS in operation. Considering that no significant difference occurred between any test distance and controls, possibly blast-related barotrauma injuries did not occur or were extremely limited. The team considers the BAS design to be very good, and it was a valuable tool for preventing significant fish mortality. The same BAS design is expected to be employed for the demolition of the remaining marine piers.

Chapter 4. Monitoring of Nearby Structures

This chapter describes the vibration monitoring and hydrographic surveys conducted for structures near the Pier E4 and E5 implosions. Structure responses determined from the vibration monitoring are presented. For the implosions, the BART Transbay Tube and EBMUD sewer outfall pipe (Figure 4-1) both were monitored. Vibrations from the blasts also were recorded by the ground motion instrumentation already installed on the new SFOBB as part of the California Strong Motion Instrumentation Program (CSMIP), which is maintained by the Department of Conservation, California Geological Survey.

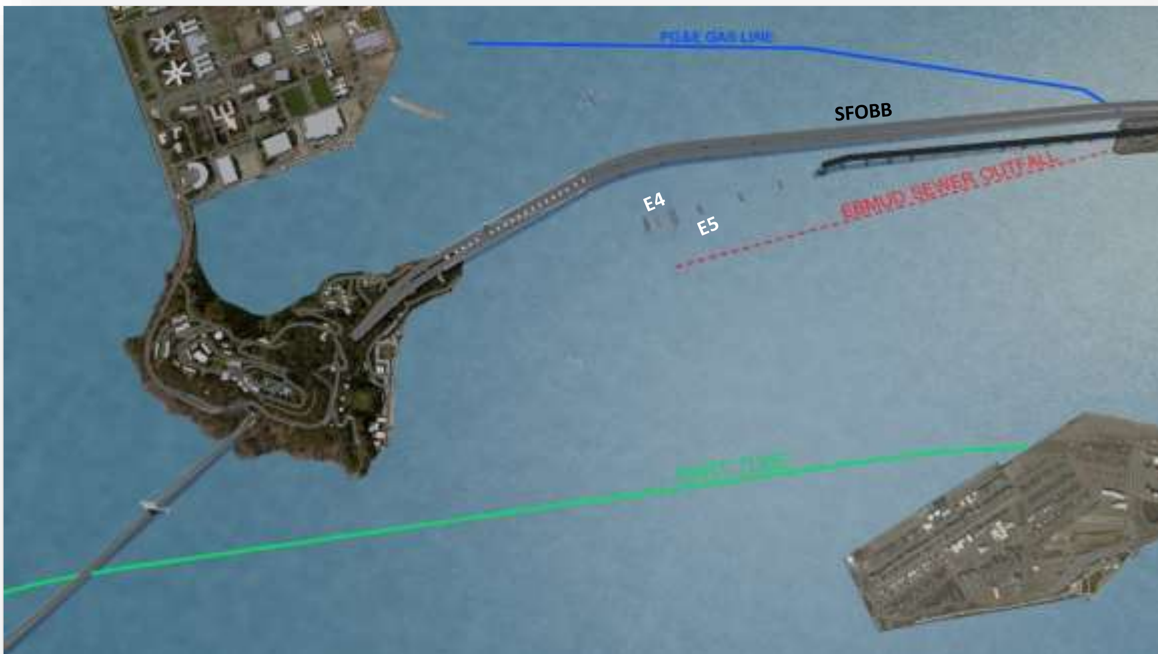


Figure 4-1. Structures near Piers E4 and E5

4.1. Vibration of BART Transbay Tube

The BART Transbay Tube is a vital link in the BART system, stretching 3.6 miles along the floor of the Bay between Oakland and San Francisco. The tube sections resemble huge binoculars in cross-section, 24 feet high and 48 feet wide, with trackways in each bore to carry trains in each direction, and separated by an enclosed central corridor for pedestrian access, ventilation, and utilities.

Figure 4-2 shows the general plan and profile of the BART Transbay Tube, which is located approximately 3,000 feet from Pier E3 and 3,400 feet from Pier E5. Vibration monitoring was undertaken during the blasts of Piers E3, E4, and E5, with vibration sensors installed on the north wall of the central corridor about 4 feet above the walkway.

Figure 4-3 shows the approximate location of the vibration sensors on the wall in a cross-section view. The vibration sensors were placed near Door No. 36 for the Pier E3 blast and near Door No. 41 for the Pier E4 and E5 blasts. These sensor locations were selected primarily by BART staff and were judged to be the closest to the blasting.

Figure 4-4 shows the vibration sensors attached to the BART Transbay Tube central corridor wall. The vibration sensors measured velocity time histories in three orthogonal directions—vertical, transverse (perpendicular to the vertical wall), and longitudinal. To ensure the quality of measurements, redundant vibration sensors also were installed. Before the blast of each pier, all systems were tested and were used to record vibrations from several passing trains. The blast of each pier successfully triggered the data acquisition system and provided digital records of vibration data. Vibration data of several passing trains also was recorded after the blast.

Figure 4-5 shows a plot of peak particle velocity (PPV) versus peak frequency resulting from the Pier E3 blast, in which blast vibrations are compared with vibrations created by passing trains. The velocity limit for BART infrastructure is shown in the figure as a black dashed line at 0.25 inches per second (in/s) with no frequency criteria. The frequency-based safe vibration criteria, as recommended by the United States Bureau of Mines (USBM) (Siskind et al. 1980), also is shown in this figure as the upper black line, established by the USBM as the 100 percent confidence limit to safe vibrations during rock blasting.

This line is the vibration limit representing the lowest possible combination of PPV and frequency that may cause threshold cracking in aboveground structures, represented by hairline cracking in drywall and plaster, which is considered to be the weakest material found in residential structures. The upper limit to concrete cracking also is shown, as a horizontal red line at 8.0 in/s. Similar data is shown in Figures 4-6 and 4-7 for the Pier E4 and E5 blasts.

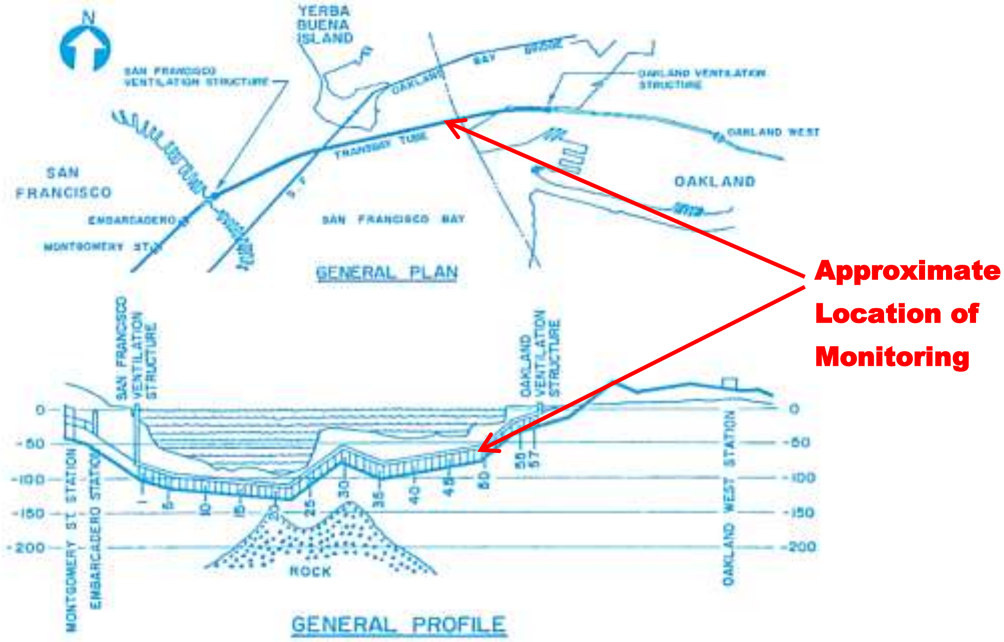
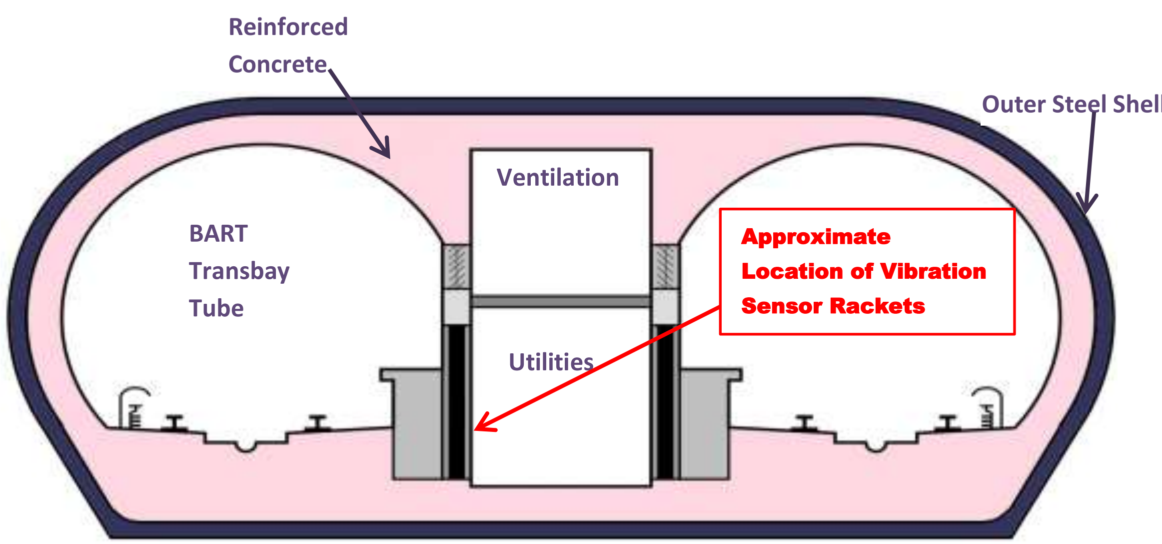


Figure 4-2. Location of Vibration Monitoring on Plan and Profile View of the BART Transbay Tube



Vibration sensors are attached to the central corridor, about 4 feet above the walkway.

Figure 4-3. Location of Vibration Monitoring on the BART Transbay Tube Cross Section

Figure 4-4. Vibration Sensors on the BART Transbay Tube Wall

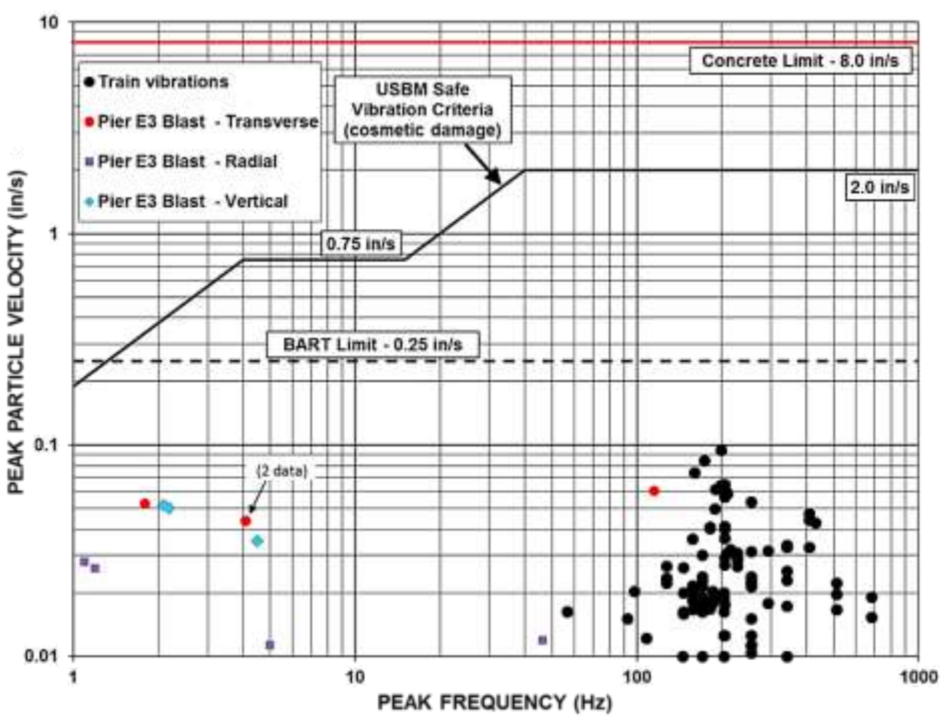


Figure 4-5. Pier E3, BART Transbay Tube Wall Vibrations vs. Frequency for Train and Blast

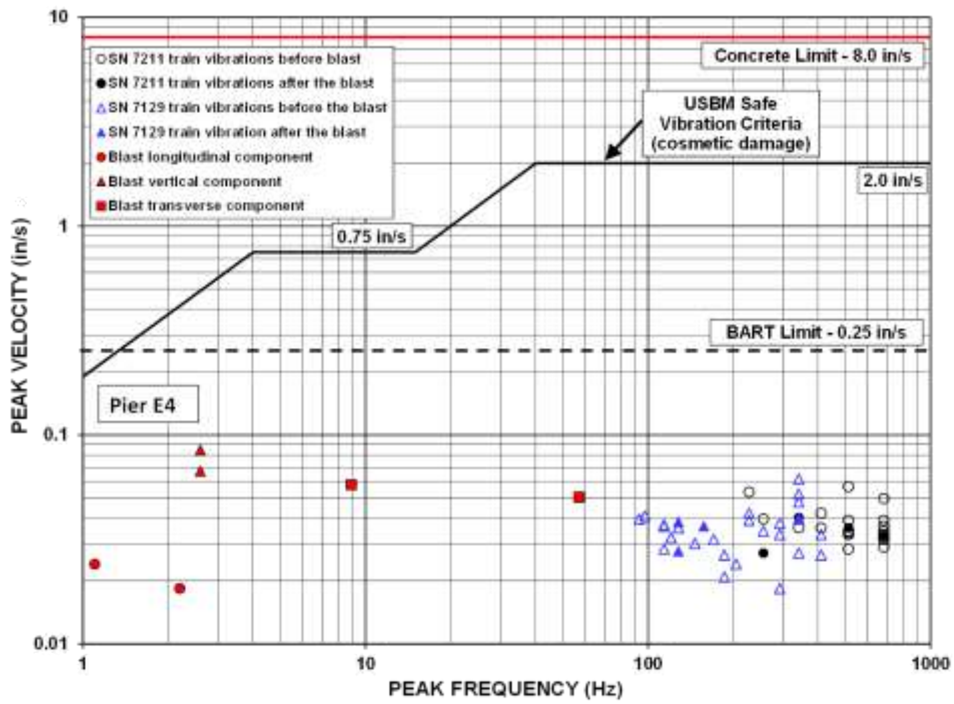


Figure 4-6. Pier E4, BART Transbay Tube Wall Vibrations vs. Frequency for Train and Blast

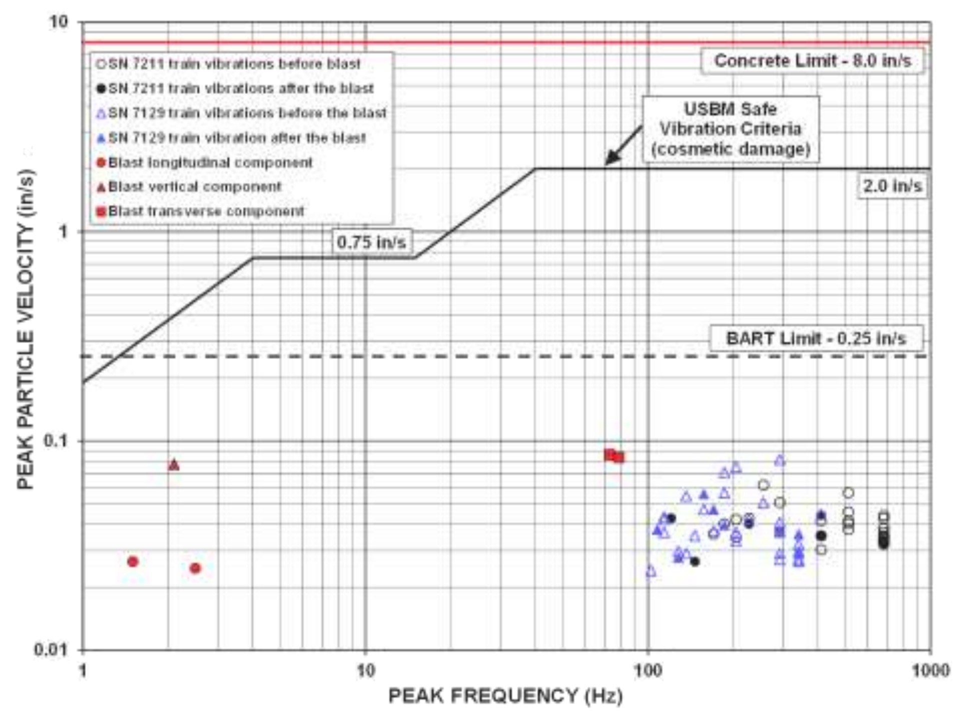


Figure 4-7. Pier E5, BART Transbay Tube Wall Vibrations vs. Frequency for Train and Blast

For a comparison, Figure 4-8 shows the acceleration response spectrum from Pier E3 blast vibration measured in the BART Transbay Tube plotted with the BART Lower Level Design Basis Earthquake (LDBE) criteria for Soil Type B/C and two recent earthquake records (i.e., the 1989 Loma Prieta earthquake recorded at YBI, and the 2014 South Napa earthquake recorded at Burma Road). The blast vibration is clearly well below the BART design criteria and the two earthquake measurements.

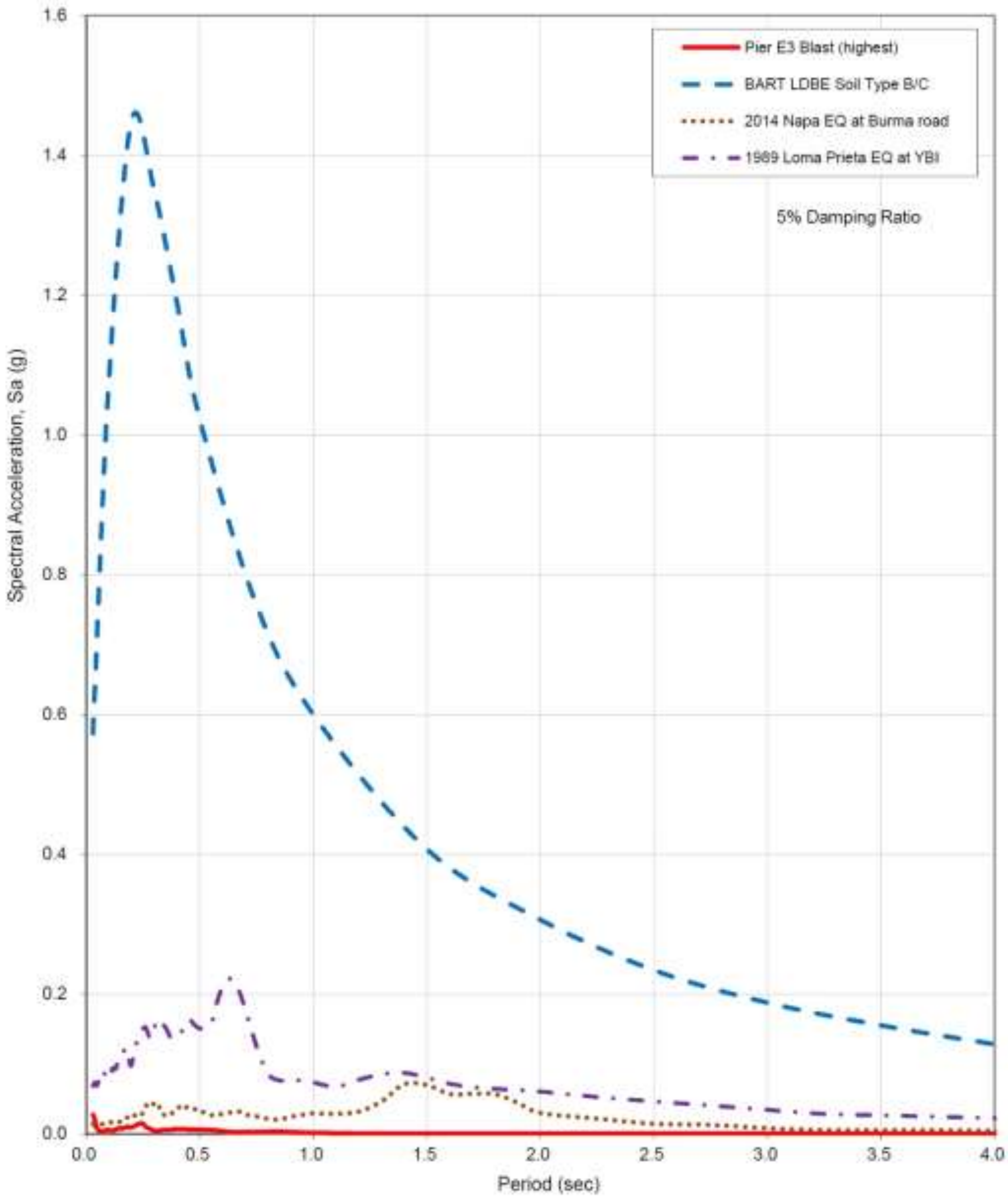


Figure 4-8. Pier E3, Blast Vibration, Earthquake Records, and BART Design Criteria

The magnitude of central corridor movement can be characterized by the recorded wall displacement from the blast. In all cases, the maximum transient wall displacement was about 0.008 in., but no permanent displacement occurred. To put that amount of displacement into perspective, the thickness of one sheet of copy paper is 0.004 inches.

4.2. Vibration of the EBMUD Sewer Outfall Pipe

The EBMUD sewer outfall pipe originates from the East Bay and terminates south of Pier E4, running parallel to the SFOBB alignment. The outfall is located approximately 500 feet south of Piers E4 and E5. Instrumentation on the outfall pipe was conducted for blasting of these two piers. However, no instrumentation or monitoring of the outfall pipe was made during the blasting of Pier E3.

The outfall pipe is buried under Bay mud from the East Bay to just south of Pier E6, and it is exposed after this point to its termination, allowing diffuser nozzles to disperse treated sewage water into Bay water. Figure 4-9 shows a cross section of the diffuser pipe. The pipe has an internal diameter of 96 inches and a diffuser nozzle every 9 feet along the length of the outfall. One-half of the outfall pipe cross section is embedded in a gravel bed with a rock fill cover.

Blast vibration measurements of the outfall pipe were made at three monitoring points (MP)—MP1, MP2, and MP3—as shown in Figure 4-10. One tri-axial velocity geophone and one tri-axial accelerometer were epoxied together and attached to a diffuser opening at each of the three monitoring locations, using a clamp. Figure 4-11 shows the geophone and accelerometer that were used for monitoring.

MP3 is the westernmost location, at the end of the outfall pipe and closest to Pier E4. MP2 is 228 feet east of MP3 and is closest to Pier E5. MP1 is 228 feet east of MP2. The locations of the sewer pipeline alignment and each monitoring point were determined using hydrographic surveying, performed by eTrac Inc.

In addition, three tri-axial accelerometers, epoxied in PVC pipe, were inserted into the Bay mud substrate approximately 20 feet north of the pipeline, outside the crushed rock fill foundation, shown as the blue square in Figure 4-9. Unfortunately, all the tri-axial accelerometers failed to register any reading during the Pier E5 blast, but the tri-axial velocity geophones recorded vibration at all three monitoring points.

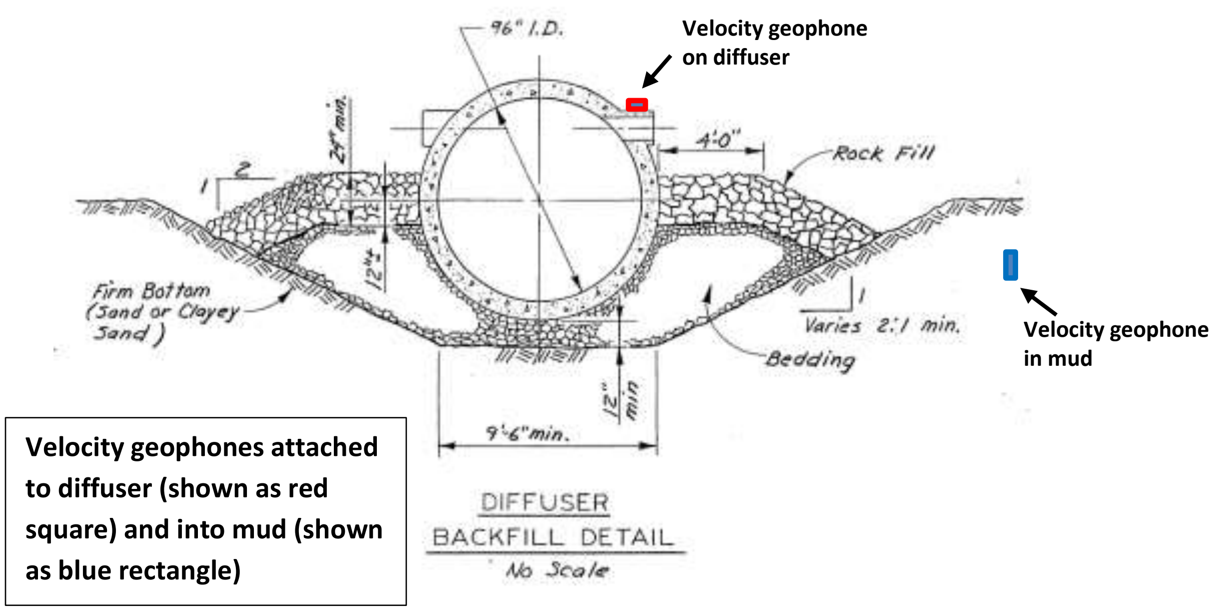


Figure 4-9. EBMUD Sewer Outfall Pipe with Velocity Geophones

Figure 4-10. EBMUD Sewer Outfall Pipe, Instrumentation Locations MP1, MP2, and MP3

The geophones are connected to the black cables; the accelerometers are connected to the blue cables.

Figure 4-11. Geophone and Accelerometer

Table 4-1 summarizes measured and calculated peaks from the three tri-axial geophones attached to the outfall pipeline during the Pier E5 blast; only the maximum value from three orthogonal directions is reported in the table. The table also includes the calculated peak displacements (absolute maximum of integrated velocity time-history) and accelerations (absolute maximum of differentiated velocity time-history).

Table 4-1. Pier E5, Peak Measured and Calculated Amplitude Summary

Date	Time (local)	Serial No.	Location	PPV (in/s)	Peak Freq. (Hz)	Peak Displace. (in.)	Peak Acceler. (g)
10/15/2016	11:56	7331	MP1-East	0.820	2.1	0.0611	1.14
		7330	MP2-Center	0.847	2.2	0.065	3.55
		7332	MP3-West	0.850	2.2	0.0604	1.59

From the diver inspection following the Pier E5 blast, all accelerometers were determined to be unusable because of damage caused by boats, while the extent of damage to existing velocity geophones clamped on diffusers was unknown. The project team decided to deploy two borehole geophones in the mud at MP2 and MP3, and clamp the third geophone on the diffuser pipe at MP3 (refer to Figure 9 for locations). Geophones inserted in the mud at MP2 and MP3 were 20 feet north of the sewer pipeline. The MP3 geophone was inserted 49 inches into the mud, while the MP2 geophone could not be pushed farther than 28 inches.

The Pier E4 blast successfully triggered four seismographs connected to four geophones. The vibration data are based on measurements made with the geophones attached to the outfall diffusers and inserted into the mud as recorded by the velocity data acquisition systems at MP2 and MP3. Table 4-2 summarizes the measured peak velocities and associated peak frequencies at each MP on the pipeline and in the mud.

The vibration measurements on the EBMUD sewer outfall pipeline indicated that the pipeline experienced no permanent displacement. In addition, hydrographic surveys performed by eTrac before and after the blasts showed no displacement of the pipeline (Figure 4-12). The maximum transient displacement resulting from the blast that was monitored was approximately 0.06 inches (about the thickness of a penny). The measured vibration in terms of peak velocity is well below a concrete cracking limit of 8 inches per second.

Table 4-2. Pier E4, Peak Measured and Calculated Amplitude Summary

Date	Time	Serial No.	Location	Deployment Type	PPV (Inches per second)	Peak Frequency (hertz)	Calculated Peak Displacement (inches)	Calculated Peak Acceleration (g)
10/29/2016	11:22	7334	MP3	Mud	0.962	7.6	0.0378	0.889
		7332		Sewer	0.815	3.2	0.0326	1.56
		7343	MP2	Mud	0.650	3.0	0.0236	1.06
		7331		Sewer*	0.243	2.5	0.0083	0.444

Note:

MP2 deployed in the sewer measured the transverse component only.

4.3. Vibration of New East Span

The new SFOBB East Span is located a short distance from Piers E3, E4, and E5. Pier E3 is about 400 feet from the new East Span, and Piers E4 or E5 are about 600 feet away.

The new bridge has been fitted with ground motion instrumentation as part of the CSMIP, which is maintained by the Department of Conservation, California Geological Survey.

The objective of the CSMIP is to monitor strong ground motions on the bridge, when it is subjected to future earthquakes. The instrumentation has been configured to automatically record vibrations with a pre-set triggering level during earthquakes. On the day of demolition for each of the piers, the triggering level was reduced to capture small vibrations induced by the controlled blasting. Indeed, the vibrations were very minor. For example, the largest recorded vibration during the blasting of Pier E3 was 0.033 gravitational acceleration units (g) at the top of tower leg and 0.005 g at the base of the tower for the Self-Anchor Suspension bridge. Similar order of magnitude or smaller vibrations were noted elsewhere along the new bridge.

As recorded by USGS, the pier implosions registered as roughly magnitude 2 earthquakes, which generally are too small to be felt by people. Most earthquakes less than magnitude 3 are not felt. The SF Bay experiences hundreds of earthquakes less than magnitude 3 every year. See Table 4-3 for USGS recorded magnitudes for Piers E3, E4 and E5.

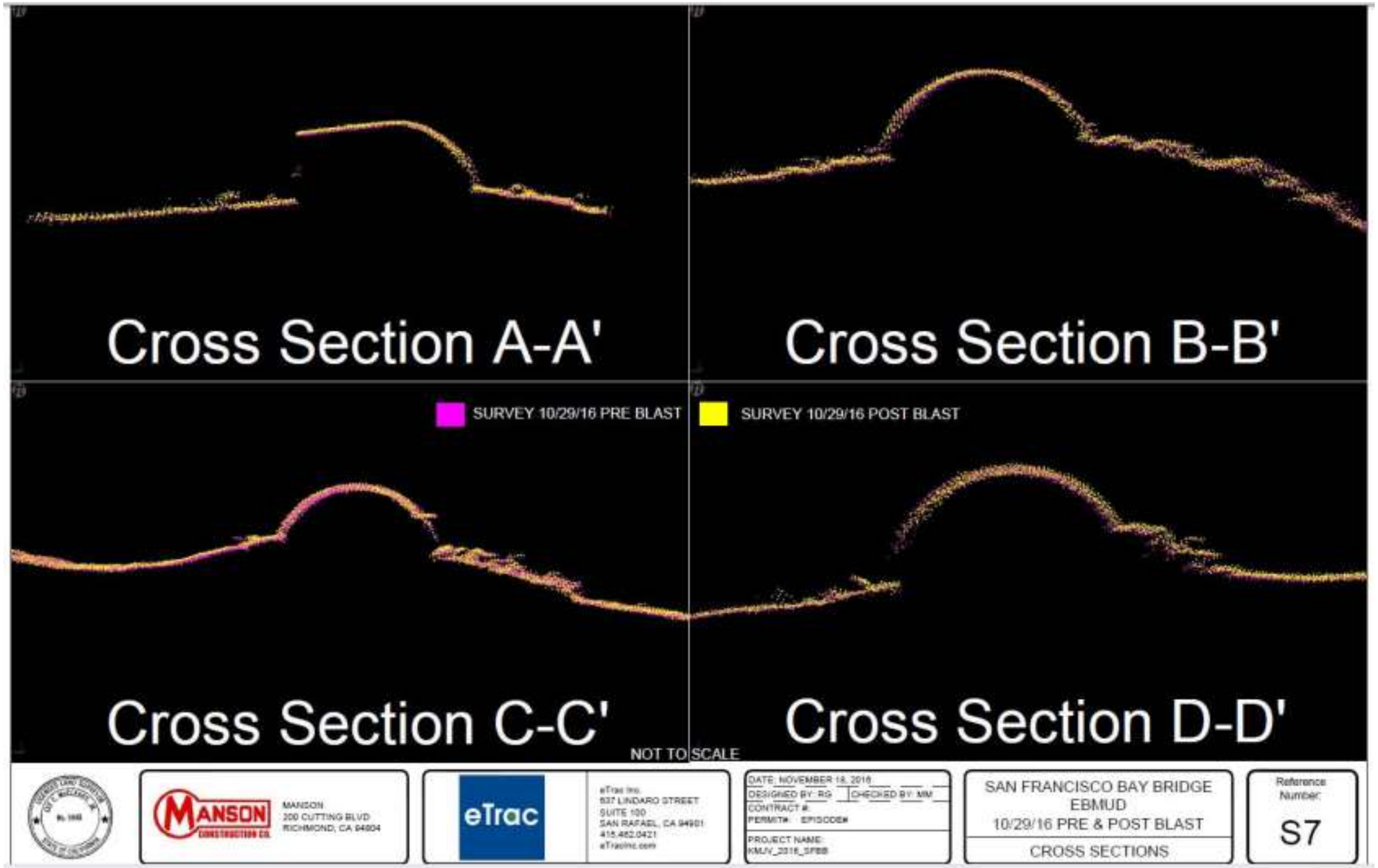


Figure 4-12. eTrac Hydrographic Survey of EBMUD Sewer Outfall Pipe, Pre- and Post-Blast

Table 4-3. USGS Records of Piers E3, E4, and E5 Implosions

Date and Time (UTC)	Latitude	Longitude	Equivalent Earthquake Magnitude	Location	Event
2015-11-14 T15:16:54.560Z	37.81583	-122.354	2.09	6 kilometers (km) west-southwest of Emeryville, California	Pier E3 Implosion
2016-10-15 T18:56:35.030Z	37.822	-122.356	1.54	6 km west of Emeryville, California	Pier E5 Implosion
2016-10-29 T18:22:24.780Z	37.8205	-122.357	1.82	6 km west of Emeryville, California	Pier E4 Implosion
Source: USGS 2016					

The project team called on the CHP to temporarily halt traffic on the new SFOBB during the blasts. Traffic was stopped to avoid potential driver surprise and accidents, as the blasts were expected to be audible to drivers. The motions caused by the blast events were quite small compared to the structural capacity of the bridge. The CHP repeatedly displayed an excellent ability to slow, stop, and restart traffic in support of blast windows.

4.4. Vibration of Pacific Gas and Electric Company Gas Line

No vibration measurements were made on the Pacific Gas and Electric Company (PG&E) gas line for the Pier E3, E4, and E5 blasts. The blast-induced vibration was expected to be very minor for the gas line because it is approximately 2,000 feet away from Pier E5. However, as the blasting proceeds toward the east, the distances to the PG&E gas line from the pile support piers will become shorter, and distances as close as a few hundred feet will be found from the easternmost pier. The design team has recognized the importance of the gas line's safe performance and continues to develop a strategy to monitor the vibration as well as to evaluate the integrity of the gas line. Based on the various vibration measurements from Piers E3, E4 and E5, the design team plans to perform vibration simulation on the PG&E gas line and develop an instrumentation program to be used for the blasting of the remaining pile-supported piers.

Chapter 5. Impacts on Water Quality and Air Quality Observations

This chapter describes the monitoring efforts that were conducted during the implosion of Piers E4 and E5 to assess any impacts on water quality. A brief discussion of air quality observations from the pier implosions is included at the end of this chapter.

5.1. Description of Piers E4 and E5 Water Monitoring

Water quality monitoring activities were conducted for Piers E4 and E5 following the procedures in the Sampling and Analysis Plan (SAP) (Department 2016c). The SAP includes procedures similar to the monitoring conducted for the Pier E3 implosion, except that grab samples collected for measurement of metals were eliminated. Metals grab samples provided only limited data, and no significant changes were observed at distances from the implosion site. The hydrogen ion concentration (pH) was determined to be a more effective means to monitor implosion plume dispersion and dynamics.

Including the Pier E3 monitoring, three water quality monitoring events have occurred, each one under different current and wind/weather conditions. The Pier E3 implosion occurred at low tide slack water conditions, and thus the current moved the plume to the south after the implosion. The Pier E4 implosion occurred during the high tide slack water, and although the current was expected to move the plume to the north, the current dynamics instead moved the plume first to west of Pier E4, followed by movement to the north. The Pier E5 implosion also occurred during a high tide slack water condition, but the plume moved rapidly to the north after the implosion. Despite the occasional unexpected current direction and plume movement, the monitoring team tracked the actual plume movement using current tracking drift-drogues (drogues) (Figure 5-1), described next.

5.2. Water Quality Monitoring Activities

Three boats were deployed during each pier implosion to assist in the water quality monitoring: 1) a drogue tender deployed window-shade drogues equipped with GPS and radio transmitters that moved with the current; 2) a dynamic plume mapping boat crisscrossed the traveling plume while collecting water quality data, using the drogue position to locate the plume; and 3) a static plume-mapping boat provided monitoring redundancy in the event of equipment failure and collected stationary water quality readings in the moving plume. The static plume mapping also provided quality assurance for measurements taken by the dynamic plume-mapping boat.

Figure 5-1. Current Tracking Drift Drogue

Water quality parameters including pH, turbidity, dissolved oxygen, and salinity were measured using sondes. In addition, water quality instrumentation was deployed at four eelgrass beds near the SFOBB to monitor water quality after the pier implosions. These YSI 6920 V2 sondes were used to measure pH, turbidity, and dissolved oxygen data at the monitoring stations. Monitoring stations were set up east of Treasure Island (TI), east of YBI, adjacent to the Oakland touchdown of the east span of the new SFOBB, and along the western shoreline of the former Alameda Naval Air Station (NAS).

For the Pier E5 implosion, water quality sampling occurred on October 6–7, 2016. Although the implosion occurred on October 7, a wet run was conducted on October 6 to test equipment, coordinate the sampling activities, and understand current dynamics. This wet run was crucial to the success of the monitoring effort. Because the Bay currents change with wind, tide, and seasonal effects, observing the current dynamics the day before the implosion provided critical information for tracking the plume on the day of implosion.

On October 7, drogues (Figure 5-1) were released north of Pier E5. The current initially moved the drogues south. When the current reversed and moved north, the drogues also moved north. The dynamic and static plume monitoring boats were set up north of Pier E5. After the implosion, these boats moved quickly towards Pier E5 to measure the plume concentration immediately following the implosion.

On October 28, 2016, another wet run was conducted in anticipation of the Pier E4 implosion. This wet run was critical to monitoring the plume. On this day, the current was expected to move north after the high tide. However, the current after high tide was still for some time before moving to the west. Only after a little more time did the current finally move to the north as predicted. Based on the experience from the wet run, the water quality team was prepared to track the plume to the west and then north after implosion of Pier E4. On October 29, the water quality team followed the current's path, conducting water quality measurements as it moved west and then north.

Detailed tabulated water quality monitoring results, background readings, equipment validation and quality assurance, and processed monitoring data will be provided in a comprehensive water quality monitoring report that is expected to be available at the beginning of February 2017.

5.3. Sediment Sampling Activities

To monitor the effect of the implosion on benthic sediment habitat, sediment samples were taken before the Pier E5 implosion and after the Pier E4implosion. The "pre-implosion" samples were collected on October 6–7, 2016, and consisted of six sample points where a Van Veen sampler (Figure 5-2) scooped a sediment sample from the floor of the Bay. Sediment cores samples were prepared and sent for toxicity evaluation and measurement of concentration of metals. Post-implosion sediment samples were collected on December 6–7, 2016. Analytical results still are being evaluated, and final results will be available in the final comprehensive water quality monitoring report.

5.4. Pier E4 and Pier E5 Water Quality Monitoring

Water quality monitoring results for Piers E4 and E5 were similar to and consistent with the water quality monitoring results from the Pier E3 implosion. During all three implosions, the plume was observed to rapidly disperse, moving quickly with the current, and the water column returned to background conditions within a few hours.

Figure 5-2. Van Veen Sediment Sampling Equipment

After the Pier E3 implosion, water quality was evaluated by measuring pH, turbidity, dissolved oxygen, and temperature. Of those parameters, pH had the most significant response and pH was determined to be the water quality parameter most affected by pier implosion.

Figure 5-3 shows the observed and estimated pH measured after the Pier E3 implosion. Turbidity, dissolved oxygen, and pH also were measured during the Pier E4 and Pier E5 implosions. The pH readings after the implosions showed a pH response that had a less significant increase and a more rapid return to background conditions as compared to Pier E3.

Table 5-1 compares pH and other parameters measured during the Pier E3, E4, and E5 implosions.

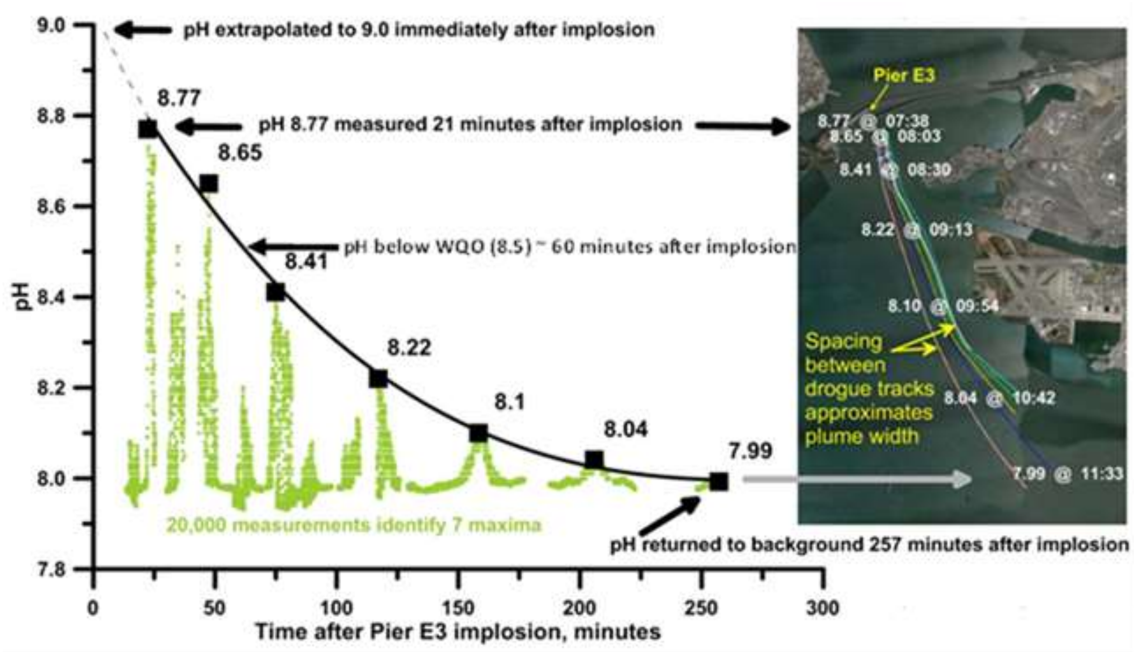


Figure 5-3. pH Measured during the Pier E3 Implosion

Table 5-1. pH and Other Water Quality Parameters Measured after the Pier E3, E4, and E5 Implosions

Pier	Maximum pH/Increase in pH	Water Quality Objectives/Background Conditions (pH)	Water Quality Parameter for which No Effects Observed	Limited Effects Observed
Pier E3	9.0 (Estimated) 8.7 (Measured) pH increased by up to 1 standard pH unit	• Below water quality objective (WQO) in approximately 1 hour • Return to background conditions in approximately 4 hours	Turbidity, dissolved oxygen, temperature	Dissolved chromium was transiently elevated above background but remained below water quality objectives
Pier E4	8.44 (Measured) pH increased by approximately 0.6 standard pH unit	• Remained in WQO range (6.5 to 8.5) during entire measurement period • Return to background conditions in less than 1 hour	Dissolved oxygen, temperature	Turbidity remained within WQO, increasing to just less than 50 NTU, and then returning to background in less than one hour
Pier E5	7.93 (Measured) pH increased by approximately 0.1 standard pH unit	• Remained within WQO range during entire measurement period • Return to background conditions in less than 1 hour	Turbidity, dissolved oxygen, temperature	No parameters

Figures 5-4 and 5-5 show the Pier E4 and Pier E5 implosion plume movements and dispersion. Drogues tracked the plumes as they moved with the current. While the drogues moved with the current, pH readings were collected at the eelgrass monitoring stations adjacent to the path of the plume. Water quality instrumentation (YSI 6920 V2 sondes) measured pH, turbidity, and dissolved oxygen levels at the monitoring stations. The observed plumes remained east of eelgrass monitoring locations adjacent to YBI and TI. The eelgrass monitoring stations adjacent to the Oakland touchdown and the former Alameda NAS were not included in these images because the plumes were not observed within any reasonable proximity of those monitoring stations. The choice was made to present pH results because as turbidity and dissolved oxygen changes were not discernable from background conditions. The turbidity and dissolved oxygen readings are consistent with the Pier E3 implosion measurements.

Each image shows the highest pH observed in the vicinity of the implosion immediately after the blast, which was 8.44 and 7.93, respectively, for Piers E4 and E5. The images show track lines of the drogues in continuous red, yellow, and green lines that originated from the pier blast area and continued north of YBI and never affected the adjacent eelgrass bed, as evidenced by the data from the five buoy monitoring locations. The change in pH from background at each monitoring station and points along the track lines when the plume was closest to each monitoring station are shown in adjacent tables. A positive change in (Δ) pH indicates a lower pH than background and a negative Δ pH indicates a higher pH than background. The comparison number used for the Δ pH along the track line is based on the highest pH observed in the vicinity of the implosion immediately after the blast.

After Pier E5 was imploded, water quality was measured at the surrounding eelgrass beds. The pH changes at the eelgrass monitoring stations throughout the monitoring period are considered negligible. The highest pH observed in the vicinity of the implosion immediately after the blast did not exceed background conditions. The highest value observed closest to the blast area and soon after the blast was approximately 7.93.

Throughout the post-Pier E4 implosion monitoring period, the pH change at the eelgrass monitoring stations is considered negligible. The highest pH observed in the vicinity of the implosion immediately after the blast was 8.44. The data shows that the pH in the plume dropped by 0.62 pH units to 7.82, which is considered the background level, by the time the plume was aligned with EG3.

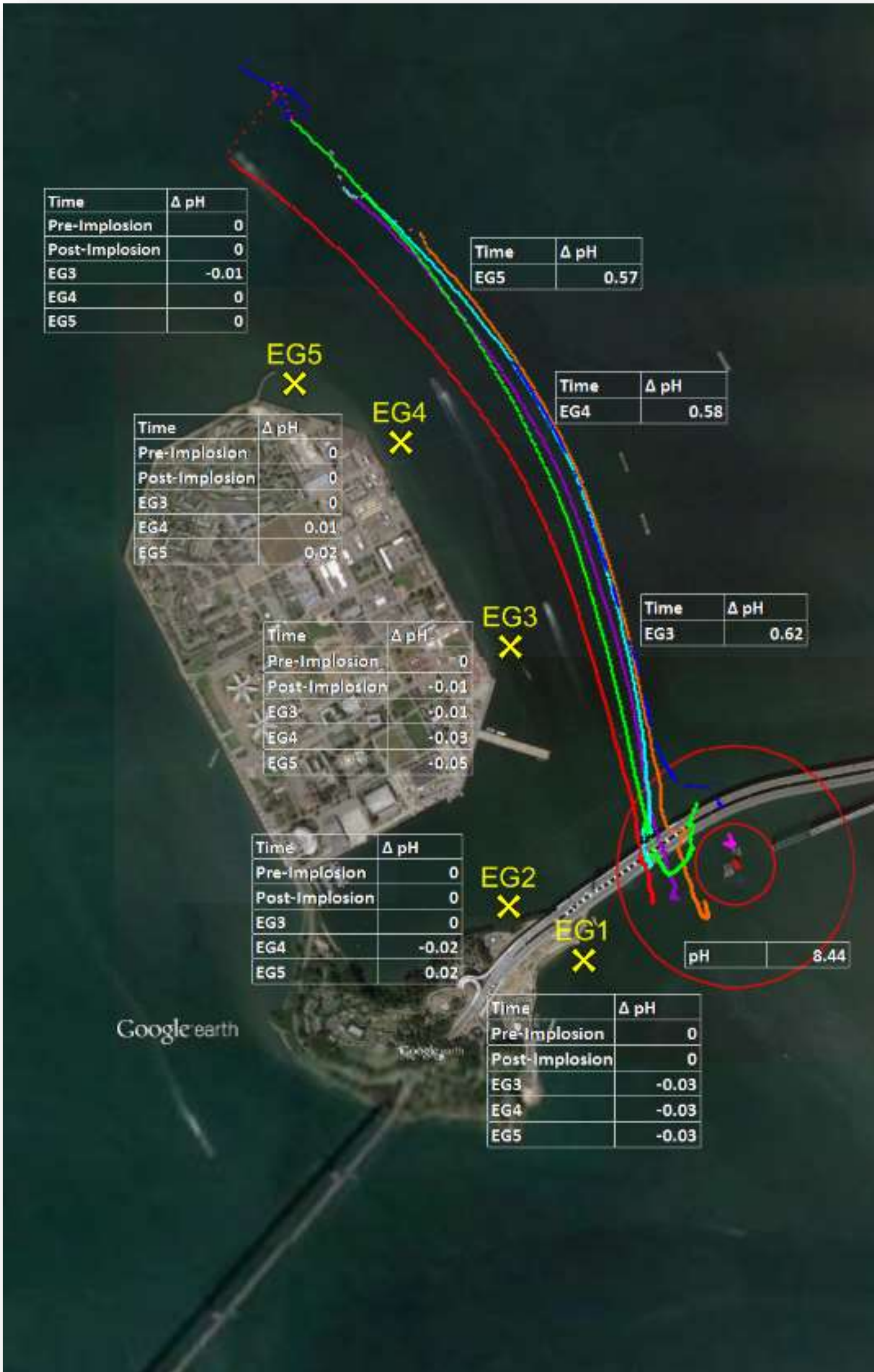


Figure 5-4. Pier E4 Implosion pH Measurements and Plume Tracking

Figure 5-5. Pier E5 Implosion pH Measurements and Plume Tracking

5.5. Water Quality Monitoring Evaluation and Conclusions

Because of the three different currents observed during the monitoring and the fact that the water quality parameters returned to background conditions rapidly after the implosions, the actual impact of the pier implosions on the SF Bay was de minimis—too trivial or minor to merit consideration. Turbidity and dissolved oxygen did not change substantially from background. The pH readings showed a slight increase from background conditions with a rapid dispersion, returning to background conditions in a short time (from half an hour to a few hours). A comprehensive water quality report is being prepared, and it will expand on this presentation.

5.6. Air Quality Observations

During both the Pier E4 and Pier E5 implosions, an air emission consisting of a yellowish orange plume with some grayish color was observed just above the pier after each implosion (Figure 5-6). This emission rapidly dispersed and settled in minutes, and completely disappeared within 10 minutes. Based on the limited extent and duration of the emission, this emission is considered de minimis.

Figure 5-6. Air Emission Following Pier Implosion

This potential water quality impact was thoroughly evaluated before the Pier E3 implosion, and the actual impact was measured right after each pier implosion. Results of that monitoring indicated that the impact was less than predicted and was limited in time and duration. The Water Quality Study, as described below, evaluated predicted impacts on water quality from the Pier E3 implosion. Those impacts were expected to be caused by sulfur, ammonia, and particulate discharges. The air plume that was observed after each pier implosion was consistent with the compounds that were expected to be released into the Bay as predicted by the Water Quality Study.

5.7. Regulatory Guidance

Regulatory approval was granted for potential water quality impacts on the SF Bay. Before the Pier E3 demonstration project, water quality was extensively evaluated and modeled, and predictions of water quality impact were presented in the Water Quality Study (Department 2015d). The RWCQB was aware of the potential impacts on water quality and accepted the implosion project methodology, provided all appropriate water quality measures were implemented as described in the amendment to the Storm Water Pollution Prevention Plan for the Pier E3 Demonstration Project (Department 2015c). The RWQCB also accepted the Pier E3 demonstration project on the condition that water quality monitoring would be conducted as described in the Sampling and Analysis Plan (Department 2015e).

After the Pier E3 implosion, results of the Pier E3 water quality measurements were presented to the RWQCB. Metal concentrations were measured during the Pier E3 implosion, which were in line with predictions. Thus, the pH measurement was proposed as the sole water quality parameter, as an indicator of a water quality impact. In preparing for the Pier E4 and Pier E5 implosions, the RWQCB reviewed the results of the Pier E3 water quality monitoring as well as the proposed best management practices and Sampling and Analysis Plan for the Pier E4 and E5 implosions, and approved the Department’s proposal.

Chapter 6. Impacts on Bay Wildlife

This chapter describes the monitoring efforts related to biological resources and includes details for hydroacoustics and marine mammal, avian, and fisheries monitoring. Hydroacoustic results for Piers E4 and E5 were compared to the modeled and measured results from Pier E3, showing less impact than originally anticipated.

6.1. Background

6.1.1. Regulatory Context

In 2015, the Department requested and received regulatory agency approvals and authorizations from USACE, USFWS, NOAA, NMFS, CDFW, the San Francisco Regional Water Quality Control Board (RWQCB), and the BCDC for use of controlled charges to dismantle the Pier E3 marine foundation of the old SFOBB East Span. The use of an in-water controlled implosion to remove a marine foundation of a bridge was the first of its kind in the Bay for the Department as well its regulatory agency partners. This Demonstration Project was to gather useful data about impacts on biological resources resulting from an innovative method of structure removal in the water in the Bay. The Pier E3 foundation was imploded on November 14, 2015, and impacts on aquatic resources were much fewer than anticipated, indicating controlled implosion was a viable option for in-water structure removal.

In 2016, following the successful implosion of Pier E3 during the Demonstration Project, the Department requested and received regulatory agency approvals and authorizations from USACE, USCG, CDFW, the San Francisco RWQCB, and the BCDC for use of controlled blasting to dismantle the marine foundations of Piers E4 through E18. In addition, Endangered Species Act Section 7 consultation was reinitiated by the Department with NMFS, to determine and obtain coverage for potential impacts on federally protected fish species, and a supplemental Biological Opinion (BO) (NMFS 2016) was issued to the SFOBB Project’s pre-existing BO (NMFS 2012). On February 29, 2016, the Department received concurrence in a letter from USCG for proposed limits of removal of Piers E2 and E4 to E22. Furthermore, the Department was issued an Incidental Harassment Authorization (IHA) from NMFS, pursuant to the Marine Mammal Protection Act (MMPA), on September 15, 2016.

6.1.2. SFOBB Biological Monitoring Programs

To minimize impacts on biological resources and determine the level of hydroacoustic noise from the anticipated upcoming implosions, the Department implemented several monitoring efforts, including hydroacoustic pressure monitoring, marine mammal monitoring, avian monitoring, fisheries monitoring, and water quality monitoring. The monitoring efforts were developed and compiled in the *SFOBB Marine Foundation Removal Project–Final Biological Monitoring Programs* (2016 Biological Monitoring Program) (Department 2016a). The 2016 Biological Monitoring Program was developed to meet the permit requirements of the project's NMFS BO, NMFS 2016 IHA, CDFW Incidental Take Permit (ITP) Amendment No. 5, and BCDC Permit Amendment No. 41. The 2016 Biological Monitoring Program, which was circulated to all the Department's partnering regulatory agencies for review and approval before finalization, discusses in detail the monitoring strategy and protocols before, during, and after the implosions of the marine foundations.

6.2. Hydroacoustic/Underwater Pressure Monitoring

Dismantling via controlled implosion was successfully demonstrated as a viable alternative to mechanical dismantling by the implosion of Pier E3 in November 2015. As with Pier E3, hydroacoustic monitoring was performed during the implosions of Piers E4 and E5 at various locations around each pier during the events. The purpose of hydroacoustic monitoring during the controlled implosions of Piers E4 and E5 were twofold: 1) to confirm the distances to specific fish and marine mammal noise impact criteria that were included in the terms and conditions of SFOBB Project permits and authorizations, estimated using the Pier E3 results; and 2) to establish a robust data set to be used in verifying and developing more efficient field monitoring methods, and to establish more accurate modeling methods for in-water blasting. In addition, a test of monitoring equipment that used blast caps (low weight explosive charges) was conducted before the Pier E4 and E5 implosions as authorized.

The criteria used to determine potential impacts on fish along the U.S. West Coast are interim thresholds for underwater impact pile driving as established by the FHWG. The FHWG includes USFWS, NMFS, the Federal Highways Administration, CDFW, the Department, the Oregon Department of Transportation, and the Washington Department of Transportation. These criteria for the onset of injury include a cumulative sound pressure level (cSEL) of 187 dBe, referenced to 1 micropascal squared per second ($\mu Pa^{2-}s^{-1}$) for fishes greater than 2 grams and 183 dBe re 1 μPa^2-s^{-1} for fishes less than 2 grams, and a single-strike peak level (L_{peak}) of 206 dBe re 1 μPa for fish of all sizes (FHWG 2008).

NMFS also includes an additional 150 dB RMS criterion as the threshold for potential behavioral response from fish from in-water impulse noise in its Biological Opinion for the SFOBB Project (NMFS 2016). Noise criteria used to regulate potential impacts on marine mammals from the implosions of Piers E4 and E5 follow the interim underwater explosive criteria established by the NMFS Office of Protected Resources, based on studies by the U.S. Navy (Finneran and Jenkins 2012), and consist of cSEL, L_{peak}, and acoustic impulse impacts with potential to cause lung injury or mortality measured by pressure over time and shown in psi per millisecond (psi-ms). The cSEL criteria for marine mammals are somewhat complex because the levels vary by species and have individual frequency weightings that also vary by species. A full list of these criteria is included in the *Marine Foundation Removal Project–Final Biological Monitoring Programs* (Department 2016a) and the *Final SFOBB Pier E3 Implosion Demonstration Project Report* (Department 2016d). These criteria are discussed in this section because they explain why hydroacoustic/blast pressure monitoring was conducted during the implosions of Piers E3, E4, and E5. Results compared to these criteria are presented in Sections 3.2.5 and 3.2.6.

Although the methodology was the same for Piers E4 and E5 as it was for Pier E3, the details of the blast plans for each pier varied by duration, the total number of explosives used, and the total weight of explosives used. The blast parameters critical to hydroacoustic impacts for all three piers are summarized in Table 6-1 The durations of the implosion events for Piers E5 and E4 were shorter than for Pier E3, with fewer individual detonations and less total weight of explosives. However, the maximum charge weight (i.e., the largest individual charge weight used) was the same for all three piers. As with Pier E3, Piers E4 and E5 were encircled with a BAS operating at the time of the implosion. Blast mats were positioned on top of the structures to control flyrock.

Table 6-1. Implosion Blast Design Parameters

Pier	Number of Individual Detonations	Range of Charge Weights (pounds)	Delay Time between Charges (milliseconds)	Duration of Implosion Event (seconds)
E3	588	21 to 35	9	5.3
E4	406	18 to 35	9	3.6
E5	298	18 to 35	9	2.7

Underwater sound levels for Pier E5 and E4 were estimated based on the results of the Pier E3 implosion. After examining the information contained in the blast plans, the underwater sound levels for Piers E5 and E4 were expected to be lower than or equal to those of Pier E3. The following discussion includes monitoring and analysis methods and the results of the controlled implosions for Piers E5 and E4.

For Piers E4 and E5, hydroacoustic/underwater pressure monitoring during pier implosions was conducted in two specific regions around the piers, each with unique methods, approaches, and plans for these regions. These regions included the "near-field" locations and the "far-field" locations. For Piers E4 and E5, the near-field locations included measurements taken within 800 feet of each pier, while the far-field locations included measurements taken between 1,500 and 4,100 feet. Because of the high overpressures expected within 500 feet, pressure transducers were required for data acquisition instead of the conventional hydrophones. In the near field, the dimensions of the piers were relatively large compared to the measurement distance. Therefore, the relationship between sound pressure and distance from the piers was complex, because the pressure from any one blast would depend not only on distance from the piers but also on the position of the blast along the face of the piers. Beyond 500 feet, sound levels were expected to display a more consistent logarithmic fall off with distance. Figure 6-1 shows the monitoring locations as planned for Piers E4 and E5.

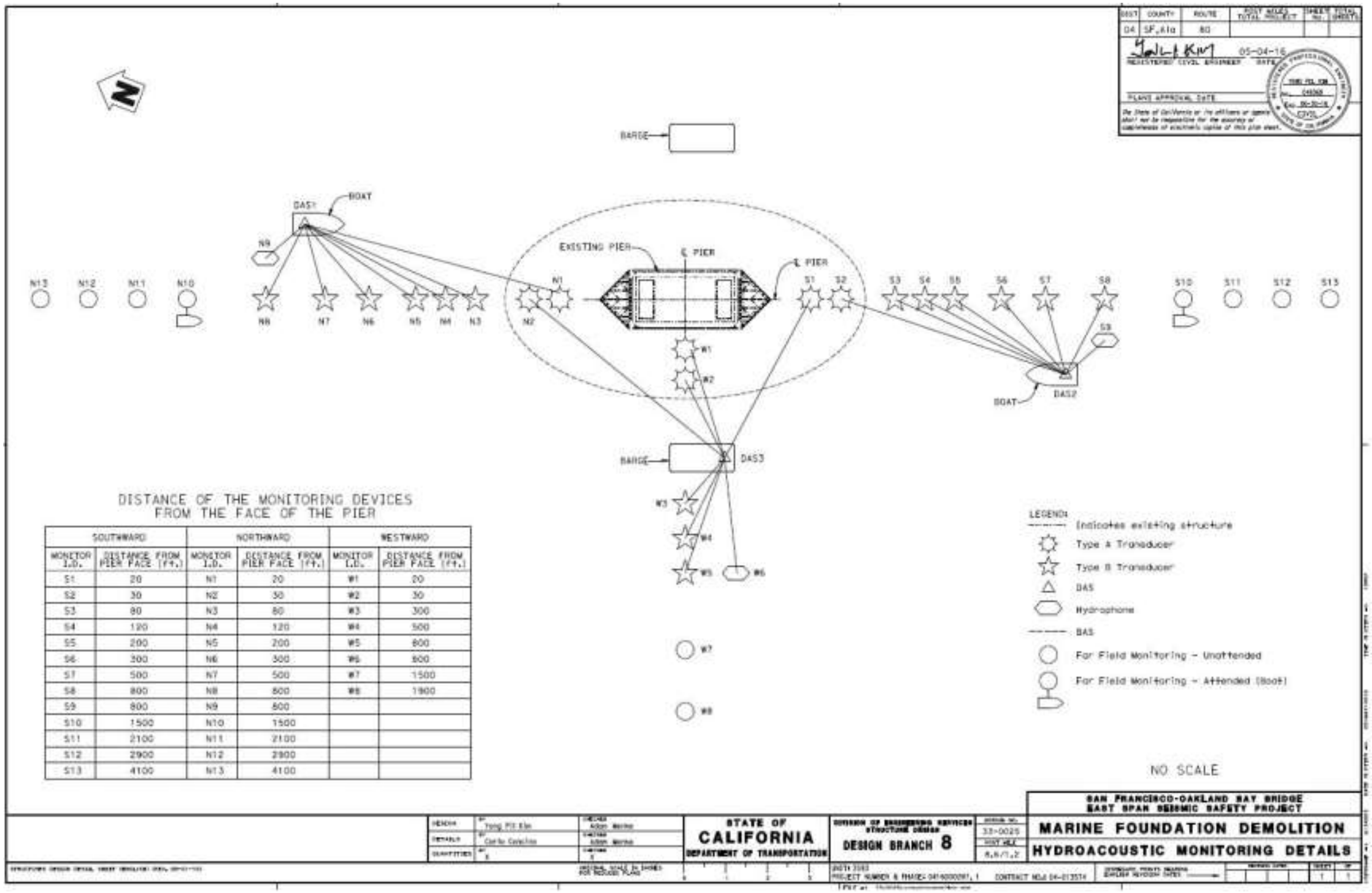
6.2.1. Monitoring Methods

For implosion events at both Piers E4 and E5, the instrumentation, acquisition procedures, and processing methods were like those used for Pier E3. The specific methods for both near- and far-field regions of Piers E4 and E5 are discussed next. The metrics necessary for comparison to the relevant fish and marine mammal criteria are peak sound pressure level, cSEL, RMS, and the acoustic impulse pressure in psi-ms. These metrics are fully defined in the *Marine Foundation Removal Project–Final Biological Monitoring Programs* (Department 2016a) and the Pier E3 report (Department 2016d).

6.2.1.1. INSTRUMENTATION

Near-Field Monitoring

Within the BAS, pressures from the implosion are very high and the rise time of the pressure signals are very short. To capture this type of signal, a high-pressure sensor recording on a high-speed data acquisition system is required. To meet this requirement, PCB 138A05 high pressure transducers were used, capable of measuring accurately up to 5,000 psi. Outside the BAS at each near-field location, PCB 138A01 pressure transducers capable of measuring accurately up to 1,000 psi were used to improve the measurement



DISTANCE OF THE MONITORING DEVICES FROM THE FACE OF THE PIER

SOUTHWARD		NORTHWARD		WESTWARD	
MONITOR I.D.	DISTANCE FROM PIER FACE (ft.)	MONITOR I.D.	DISTANCE FROM PIER FACE (ft.)	MONITOR I.D.	DISTANCE FROM PIER FACE (ft.)
S1	20	N1	20	W1	20
S2	30	N2	30	W2	30
S3	80	N3	80	W3	300
S4	120	N4	120	W4	500
S5	200	N5	200	W5	800
S6	300	N6	300	W6	800
S7	500	N7	500	W7	1500
S8	800	N8	800	W8	1900
S9	800	N9	800		
S10	1500	N10	1500		
S11	2100	N11	2100		
S12	2900	N12	2900		
S13	4100	N13	4100		

Figure 6-1. Piers E4 and E5 Proposed Hydroacoustic/Blast Pressure Monitoring Locations

resolution. Both types of transducers can capture acoustic frequencies greater than 1,000,000 hertz (Hz). Because of the design of the pressure transducers, no method existed for field calibration of either of them; the manufacturer-supplied calibration was obtained within 6 months of the first implosion of 2016, Pier E5. In addition, Reson TC4013 hydrophones with an upper acoustic frequency range of 170,000 Hz were used at the farthest nominal locations, 800 feet from the piers. As the far-field monitoring locations used hydrophones only, the 800-foot systems were used as a comparison point between the high speed/high frequency pressure transducer system and the more moderate speed hydrophone-based systems.

The voltage signals proportional to pressure for all measurements were recorded by an eight-channel MREL DataTrap II high-speed recorder, sampling at 1,000,000 samples per second (S/s) (one record per 0.001 milliseconds), per the Near-Field Hydroacoustic Monitoring Plan, as presented in *Marine Foundation Removal Project–Final Biological Monitoring Programs* (Department 2016a). With the expected rapid rise time of pressure from individual blasts in the implosion event, the sampling rate of 1,000,000 S/s was determined to be appropriate for capturing the true overpressures.

Far-Field Monitoring

At all far-field monitoring locations, Reson TC4013 hydrophones were deployed at a depth of approximately 20 feet. These transducers provide a useful upper acoustic frequency range of 170,000 Hz. Signals from the hydrophones passed through PCB 422E04 in-line charge converters. For the 1,500-foot locations, the frequency performance of the charge converters was enhanced to take full advantage of the 170,000 Hz upper range of the TC4013 hydrophones by use of PCB 482A22 signal conditioners that boosted the current supplied to the charge converters. These signals were recorded with Astro-Med TMX multi-channel data acquisition systems, which captured the voltage signals proportional to pressure along the north and south monitoring arrays. These units record at a sampling rate of 500,000 S/s. The output of each system was split and fed into two channels of the recorder set to two different voltage ranges to capture an optimal signal. The TMX systems were programmed to trigger by the incoming signal of blast sequence. This trigger was manually armed by hydroacoustic monitoring personnel located at each position. The TMX system did not have internal electrical power and had to be powered at 24 volts direct current (DC) from two heavy-duty 12-volt DC batteries hooked in series. The signals were further split at the TMX recorder so that they could be captured with solid state Roland R-05 audio recorders, sampling at 96,000 S/s. This provided a back-up to the high-speed recorders and a comparison between the two recorders. Compared to the high-pressure transducers, the hydrophone systems are more sensitive, provide less electronic noise floor issues, and are more suitable for the lower levels estimated at the distant locations.

At each of the other far-field locations, unmanned autonomous units were deployed at least 1 hour before the implosions. These units consisted of a TC4013 hydrophone, a PCB 422E13 charge converter, and a PCB 480E09 signal conditioner, all housed in a water-tight cylindrical case about 5 inches in diameter and 12 inches long. The units were deployed on a rope with a weight on the end near the container, and the other end secured to a line between a float and an anchored buoy positioned before the blast. The Roland recorders have sufficient memory so that triggering was not needed, because they can record continuously for up to about 12 hours. Each autonomous unit was positioned at a depth of approximately 20 feet.

Table 6-2 shows the locations where sensors were deployed and indicates the locations where usable data was collected. Further clarification on these monitoring locations is presented in Section 6.3.2.

6.2.1.2. TEST BLAST

Capturing the acoustic results of the implosions was a critical monitoring component to determine potential impacts on biological resources in the Bay. A key factor in accurately capturing hydroacoustic information was to ensure triggering of the data acquisition and recording instruments. The instruments used high-speed recording devices during near-field and far-field monitoring. To this end, the pressure-time signature of a blast could not be duplicated except with another blast. Thus, release of small test charges was required to verify and confirm that all equipment was functional and to set the triggering parameters accurately for an implosion. The Department discharged two test charges at separate times within a single day of testing on Friday November 7, 2016, during separate events. These tests occurred while the BAS was in operation. During pre-blast testing of hydroacoustic monitoring equipment, ambient noise and background data were collected successfully. A break-wire trigger system was tested successfully on three independently deployed data acquisition systems during the detonation of a single blasting cap for two separate events. The BAS was placed 50 feet from Pier E5, and pressure sensors were deployed at distances of 10, 20, 30, 80, and 100 feet from the single detonators, in north and west directions. All data was collected during a low-water slack tide.

Table 6-2. Piers E4 and E5 Planned and Deployed Monitoring Locations

Array	Location Name	Pier E4 Planned Distance from Pier (feet)	Pier E4 Deployed Distance from Pier (feet)	Pier E4 Usable Data Collected (Yes/No)	Pier E5 Planned Distance from Pier (feet)	Pier E5 Deployed Distance from Pier (feet)	Pier E5 Usable Data Collected (Yes/No)
North	N1	20	20	Y	20	23	Y
	N2	30	28	Y	30	30	Y
	N3	80	80	N	80	84	N
	N4	120	160	Y	120	124	Y
	N5	200	210	Y	200	200	Y
	N6	300	297	Y	300	300	Y
	N7	500	492	Y	500	505	N
	N8	800	809	Y	800	805	Y
	N9	800	809	Y	800	805	Y
	N10	1,500	1,500	Y	1,500	1,500	Y
	N11	2,100	2,142	Y	2,100	2,100	N
	N12	2,900	2,739	Y	2,900	2,750	Y
	N13	4,100	3,600	Y	4,100	3,760	Y
South	S1	20	18	Y	20	20	Y
	S2	30	26	N	30	29	N
	S3	80	80	N	80	70	Y
	S4	120	121	N	120	108	Y
	S5	200	193	Y*	200	183	Y
	S6	300	295	Y*	300	286	Y
	S7a	500	500	Y*	500	488	Y
	S7b	500	500	Y	NA	NA	NA
	S8	800	799	N	800	785	Y
	S9	800	799	Y	800	785	Y
	S10	1,500	1,687	Y	1,500	1,500	Y
	S11	2,100	2,315	Y	2,100	2,094	N
	S12	2,900	3,268	Y	2,900	2,896	Y
	S13	4,100	4,182	Y	4,100	4,191	Y
West	W1	20	21	Y	20	20	Y
	W2	30	31	Y	30	30	Y
	W3	200	142	N	300	275	Y
	W4	300	194	N	500	448	N
	W5	NA	NA	NA	800	740	Y
	W6	NA	NA	NA	800	740	Y
	W7	1,500	1,502	Y	1,500	1,424	Y
	W8	1,900	1,945	Y	1,900	2,123	Y

*Results used to report overpressures only, data was not usable to report cSEL or RMS

6.2.1.3. PIER E5 IMPLOSION

Measurement Locations

Near-Field Monitoring

The near-field monitoring plan consisted of 24 total monitoring locations in the north, south, and west directions from Pier E5, which included six monitoring locations within the BAS and three locations with a hydrophone sensor positioned with a pressure transducer. Each measurement was taken at depths of approximately 20 feet below the water surface. Table 6-2 shows a diagram of all monitoring locations. Near-field monitoring locations are labeled N1 through N9 in the north and S1 through S9 in the south direction and W1 through W6 in the west. Near-field monitoring was triggered electronically from the signal used to initiate the blast, and therefore was time-synchronized with the detonation sequence.

For the Pier E5 implosion event, sensors were deployed approximately as shown in the monitoring plan and data was successfully acquired at 20 locations along all three lines, as shown in Figure 6-2.

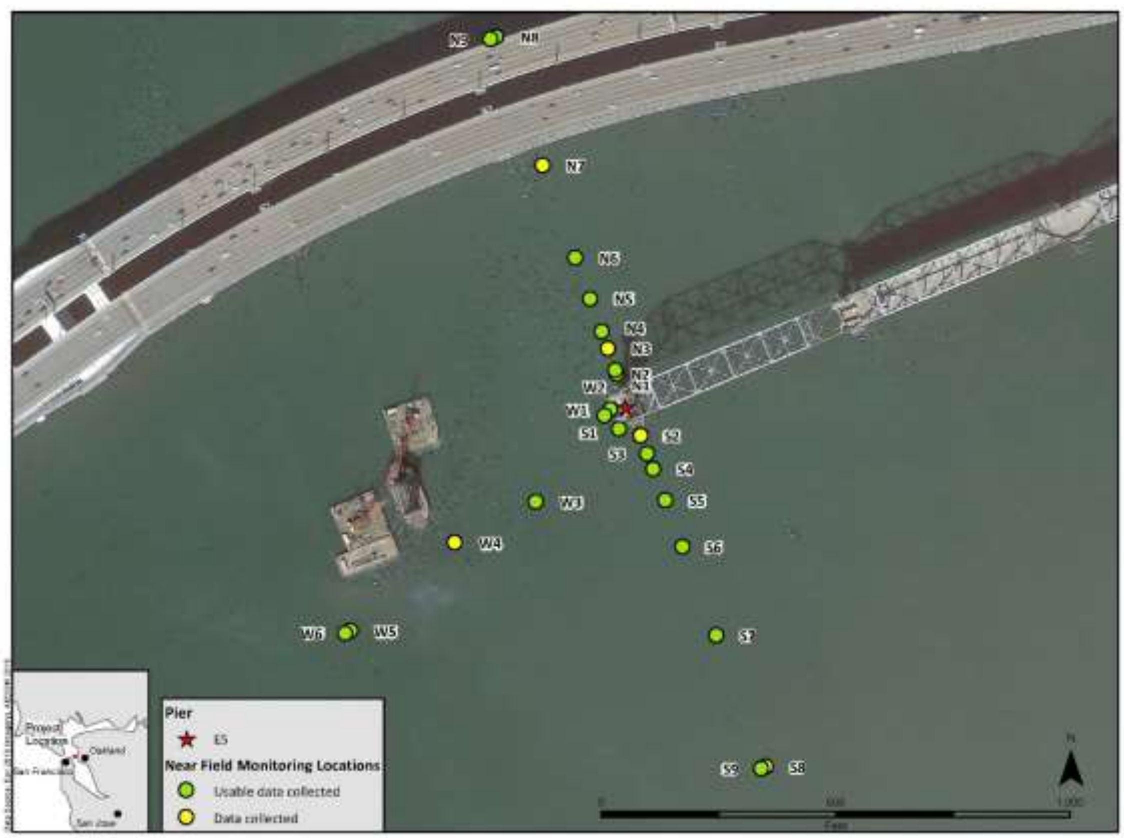


Figure 6-2. Pier E5 Deployed at Near-Field Monitoring Locations Where Data Was Collected

Far-Field Monitoring

Far-field monitoring was planned at 10 locations along the same north, south, and west lines as the near-field locations. Figure 6-1 shows each of the planned far-field measurement locations. Each of the far-field measurements was made with hydrophones positioned approximately 20 feet below the water surface.

For the Pier E5 implosion event, data was successfully captured at eight locations, as shown in Figure 6-3. Successful measurements were made at the locations indicated in Table 6-3.

Figure 6-3. Pier E5 Deployed at Far-Field Monitoring Locations Where Data Was Collected

Table 6-3. Hydroacoustic Monitoring Results for Pier E5

Location Name	Distance (feet)	Overpressure Level (psi)	Peak Sound Pressure Level (dBp)	cSEL (dBe)	RMS Pressure Level (dB)	Impulse (psi/ms)
N1	23	1458.70	260.0	228.0	223.7	437.3
N2	30	1120.70	257.8	223.0	218.7	318.9
N4	124	35.21	227.7	204.3	200.0	32.0
N5	200	29.50	226.2	198.8	194.5	13.0
N6	300	16.76	221.3	197.8	193.5	13.7
N8	805	3.00	206.3	186.0	181.7	1.7
N9	805	2.49	204.7	185.3	181.0	1.8
N10	1500	0.78	194.7	170.1	165.8	0.5
N12	2750	0.45	189.8	168.3	164.0	0.3
N13	3760	0.31	186.6	168.3	164.0	0.3
S1	20	210.40	243.2	213.0	208.7	62.8
S3	70	16.60	220.0	203.5	199.2	10.5
S4	108	18.69	222.0	197.1	192.8	12.9
S5	183	7.41	214.7	196.4	192.1	6.8
S6	286	5.33	210.5	193.6	189.3	6.5
S7	488	2.40	203.9	191.3	187.0	6.1
S8	785	2.39	203.5	191.7	187.4	3.1
S9	785	1.91	203.5	191.3	187.0	2.9
S10	1500	0.57	194.3	181.4	177.1	0.8
S12	2896	0.40	188.7	172.8	168.5	0.5
S13	4191	0.22	183.7	170.6	166.4	0.3
W1	20	314.50	246.6	216.4	212.1	62.7
W2	30	180.40	241.9	213.2	208.9	43.8
W3	275	2.11	204.4	193.8	189.5	2.9
W5	740	2.05	200.4	191.6	187.3	3.8
W6	740	0.97	197.8	187.2	182.9	1.7
W7	1424	0.19	180.2	169.4	165.1	0.3
W8	2123	0.17	179.4	170.4	166.1	0.3

Notes:

psi = pounds per square inch; dB = decibel; dBp = decibel in pressure; dBe = decibel in energy; cSEL = cumulative sound exposure level; RMS = root mean square; psi/ms = pound per square inch per millisecond

Source: Illingworth and Rodkin 2016

6.2.1.4. PIER E4 IMPLOSION

Near-Field Locations

The near-field monitoring plan consisted of 23 monitoring locations in the north, south, and west directions from Pier E4. Each measurement was taken at depths of 20 feet below the water surface. For the implosion of Pier E4, the near-field monitoring locations were somewhat altered from those shown in Figure 6-1. Table 6-2 summarizes the planned and deployed monitoring locations. The measured locations of the near-field monitoring are shown in Figure 6-4.

The same high-speed systems used for Pier E5 at the west, north and south arrays were used for Pier E4. Near-field monitoring systems were triggered electronically directly by the signal used to initiate the blast, and therefore were time-synced with the detonation sequence. For the Pier E4 implosion event, data was successfully acquired at 13 locations along all three lines, as shown in Figure 6-4. Table 6-2 summarizes the monitoring locations.

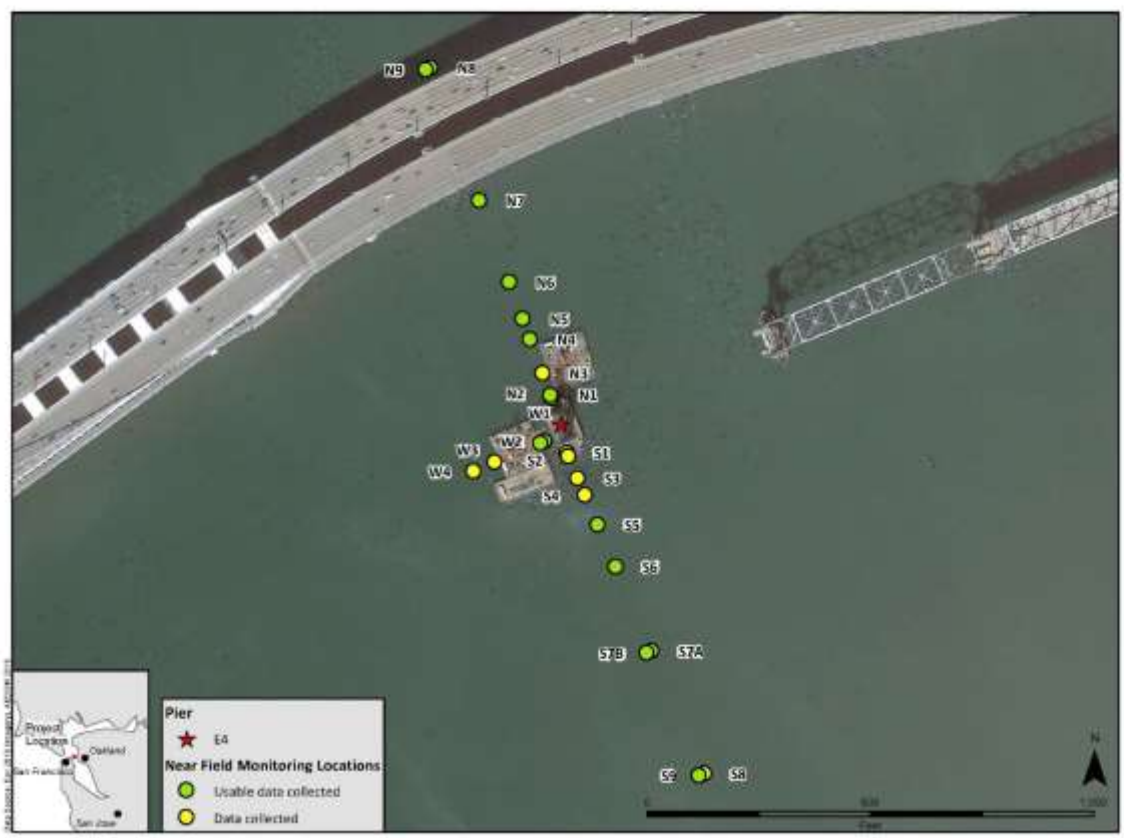


Figure 6-4. Pier E4 Deployed at Near-Field Monitoring Locations Where Data Was Collected

Far-Field Locations

Far-field monitoring for Pier E4 was planned at the same 10 locations discussed for Pier E5 along the north, south, and west lines, and shown in Figure 6-1. Successful measurements were made at each location, with actual distances for each directional array shown in Table 6-3. Figure 6-5 shows the measured locations made in the far-field monitoring during the Pier E4 implosion.

Figure 6-5. Pier E4 Deployed at Far-Field Monitoring Locations Where Data Was Collected

6.2.2. Test Blast Results

The same type of data acquisition system used during the implosion of Piers E5 and E4 was deployed to monitor in-water pressure levels from the single detonator, using pressure sensors and hydrophones. All equipment functioned as expected, and the “break-wire” trigger method was successfully tested. Deployment methods also were deemed successful. Background pressures measured during BAS operation were above ambient pressures as expected. Similar values were recorded in the north, away from activities on the barge, and increased to the west toward the barge beyond the BAS location. This increase was likely influenced by the “trapped” upwelling and additive effects of bubbles between the barge and pier, and cyclical compressor motor noise. Test blast underwater pressures measured inside the BAS showed overpressures substantially lower than predicted, most likely because of air bubbles from the BAS extending back to the pier wall. Slightly lower pressures were measured outside the BAS because values may have been enhanced by the proximity of the BAS and bubble reflections at the compressor barge wall. This was most apparent in background measurements to the west during the BAS operation. Construction activities on the barge from operating compressor motors may have contributed to increased ambient pressures to the west, when compared to far lower ambient pressures to the north.

6.2.3. Pier E5 Implosion Results

The Pier E5 monitoring results for each location are shown in Table 6-3. The values include overpressure in psi, peak sound pressure level in dBp, cSEL in dBe, RMS pressure level in dB, and impulse pressure in psi-ms.

6.2.4. Pier E4 Implosion Results

The Pier E4 monitoring results for each location of the near- and far-field measurement lines are shown in Table 6-4. The values include overpressure in psi, sound pressure level in dB, SEL in dB, RMS pressure level in dB, and marine mammal Level A take criteria for lung injury and mortality in psi-ms. For near-field measurement locations S5, S6, and S7A, the true peaks resulting from the implosion event were captured by the pressure transducers; however, electronic noise unassociated with the blast occurred approximately 1,800 milliseconds into the blast and lasted for approximately 200 milliseconds. For this reason, cSEL could not be calculated for these measurement locations. In addition, the data collected at W3 and W4 were not usable because too much extraneous noise contaminated the data. Table 6-2 summarizes deployed monitoring locations where usable data was collected.

6.2.5. Results Compared to Fish Criteria

The overpressure levels for all the monitoring locations from Piers E3, E4, and E5 are shown in Figure 6-6, along with the corresponding fish criteria and the data trend lines. The peak level trend line for Pier E4 is almost identical to the Pier E3 trend line at distances within 100 feet. After 100 feet, the trend line for Pier E4 reduces at a faster rate than Pier E3, and becomes closely aligned with the trend line for Pier E5 after approximately 2,000 feet. Starting at 300 feet, the trend line for Pier E4 is approximately 4 dBp below the Pier E3 trend line, while the Pier E5 trend line is approximately 7 dBp below Pier E3.

Table 6-4. Hydroacoustic Monitoring Results for Pier E4

Location	Distance (feet)	Overpressure Level (psi)	Peak Sound Pressure Level (dBp)	cSEL (dBe)	RMS Pressure Level (dB)	Impulse (psi-ms)
N1	20	952.46	256.3	223.1	212.0	211.0
N2	28	614.57	252.5	224.3	213.2	210.9
N4	160	75.24	234.3	205.9	194.8	25.1
N5	210	40.79	229.0	201.0	189.9	11.3
N6	297	16.70	221.2	196.5	185.4	0.6
N7	492	11.49	218.0	192.2	181.1	2.3
N8	809	6.28	212.7	187.1	176.0	1.7
N9	809	4.60	210.0	185.5	174.4	1.5
N10	1,500	0.65	193	176.3	165.2	0.1
N11	2,142	0.59	192.2	172.6	161.5	0.2
N12	2,739	0.56	191.7	174.9	163.8	0.1
N13	3,600	0.36	188	167.2	156.1	0.2
S1	18	242.86	244.5	213.3	202.2	81.6
S5	193	4.87	210.5	N/A[a]	N/A[a]	0.8
S6	295	2.35	204.2	N/A[a]	N/A[a]	0.6
S7A	500	1.87	202.2	N/A[a]	N/A[a]	6.4
S7B	500	1.66	201.2	189.9	178.8	5.9
S9	799	1.46	200.1	186.8	175.7	4.9
S10	1,500	0.50	190.7	177.9	166.8	1.6
S11	2,315	0.25	184.7	173.8	162.7	0.8
S12	3,268	0.24	184.4	172.2	161.1	0.7
S13	4,182	0.09	176.1	164.1	153.0	0.2
W1	21	221.04	243.7	215.1	204.0	51.5
W2	31	146.86	240.1	213.2	202.1	31.8
W7	1,502	0.50	190.8	177.0	165.9	1.4
W8	1,945	0.35	187.6	174.3	163.2	0.3

Notes:

Electronic noise in these signals during the implosion made it impossible to accurately calculate the SEL/RMS

psi = pounds per square inch; dB = decibel; dBp = decibel in pressure; dBe = decibel in energy; cSEL = cumulative sound exposure level; RMS = root mean square; psi/ms = pound per square inch per millisecond

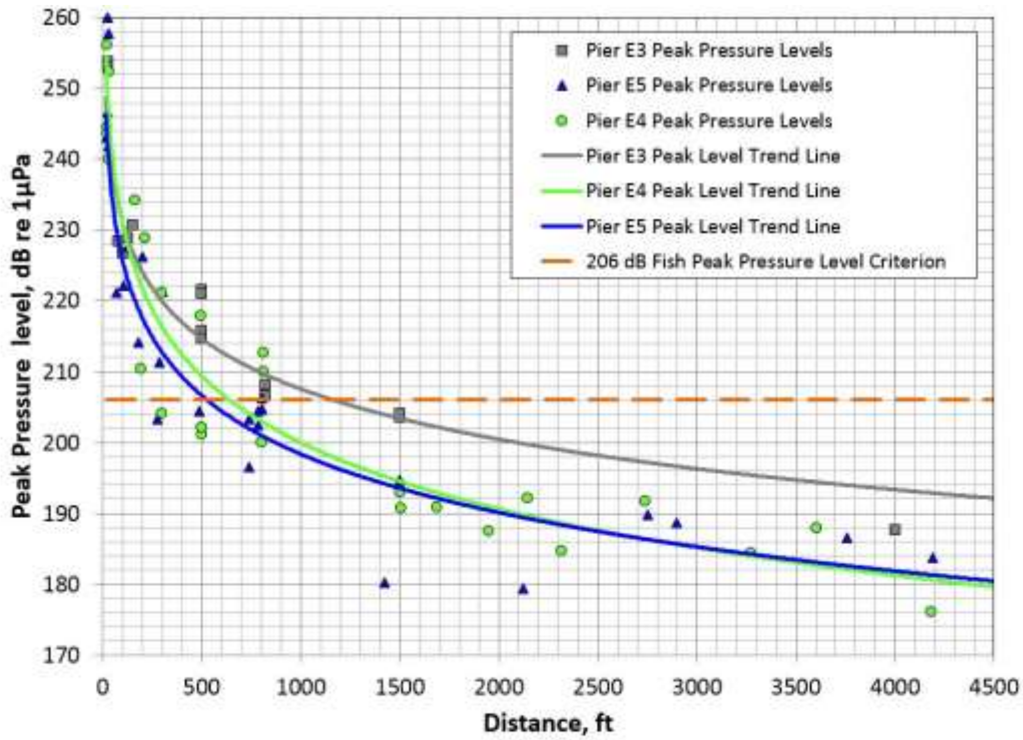


Figure 6-6. Peak Level Trend Lines for Piers E3, E4, and E5

The cSEL values for the three piers are shown in Figure 6-7. The cSEL trend lines for all three piers have less variation than the peak trend lines. The Pier E3 trend line is 2 to 4 dBe higher than the other two piers at distances within 2,500 feet. Beyond 2,500 feet, the trend lines are within 2 dB of each other. Overall, substantially less scatter is seen in the cSEL plot than in the peak level plot.

The RMS sound pressure level results are shown in Figure 6-8, along with RMS threshold and trend line of the measured data for Piers E3, E4, and E5. The fall-off rates for each pier are the same as the cSEL trend lines' fall-off rates for the corresponding pier; however, an offset is applied to each that accounts difference in implosion event duration. In Figure 6-8, each trend line is extended to a distance of 20,000 feet, which is well beyond the actual data points to show where they cross the 150 dB fish threshold. The trend line of Piers E3 and E4 are almost identical at distances within 4,000 feet. Because the time duration of the Pier E3 implosion was longer than that of Piers E4 and E5, the trend line for Pier E3 is below the other two piers starting at distances beyond 4,000 feet. The trend lines for Pier E3 and E4 are well below E5 because of the shorter time duration of the E5 implosion. This translates to a large (approximately 6,000 feet) difference in distance to threshold between Piers E3/E4 and Pier E5, although the actual received SPLs are not very different, especially between Piers E4 and E5.

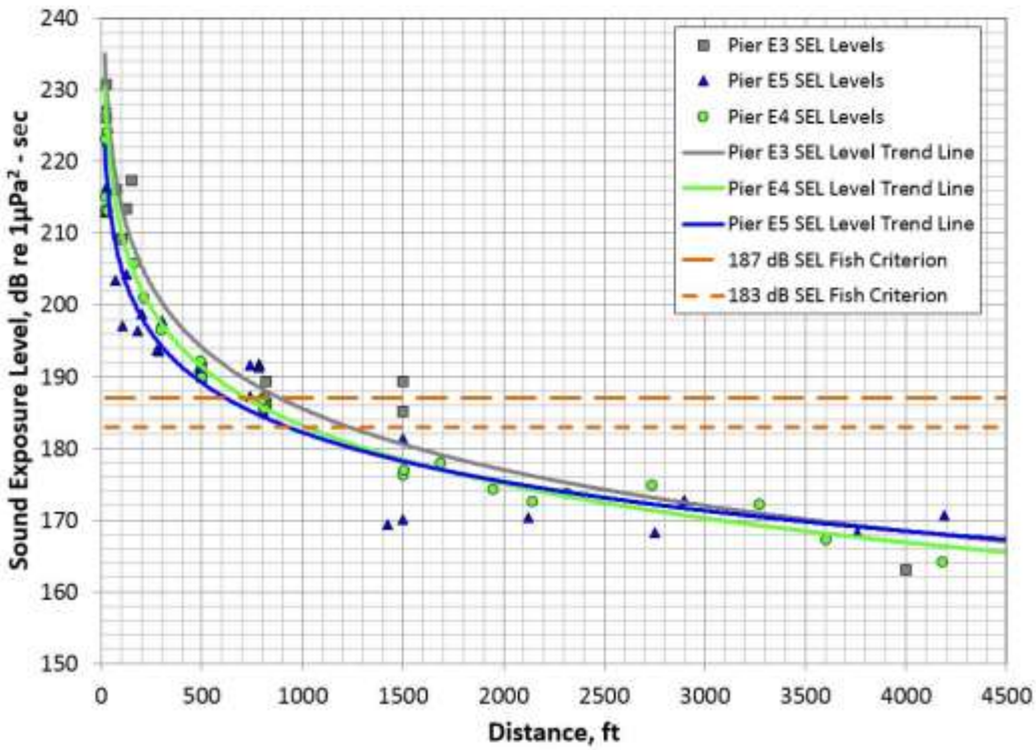


Figure 6-7. cSEL Trend Lines for Piers E3, E4, and E5

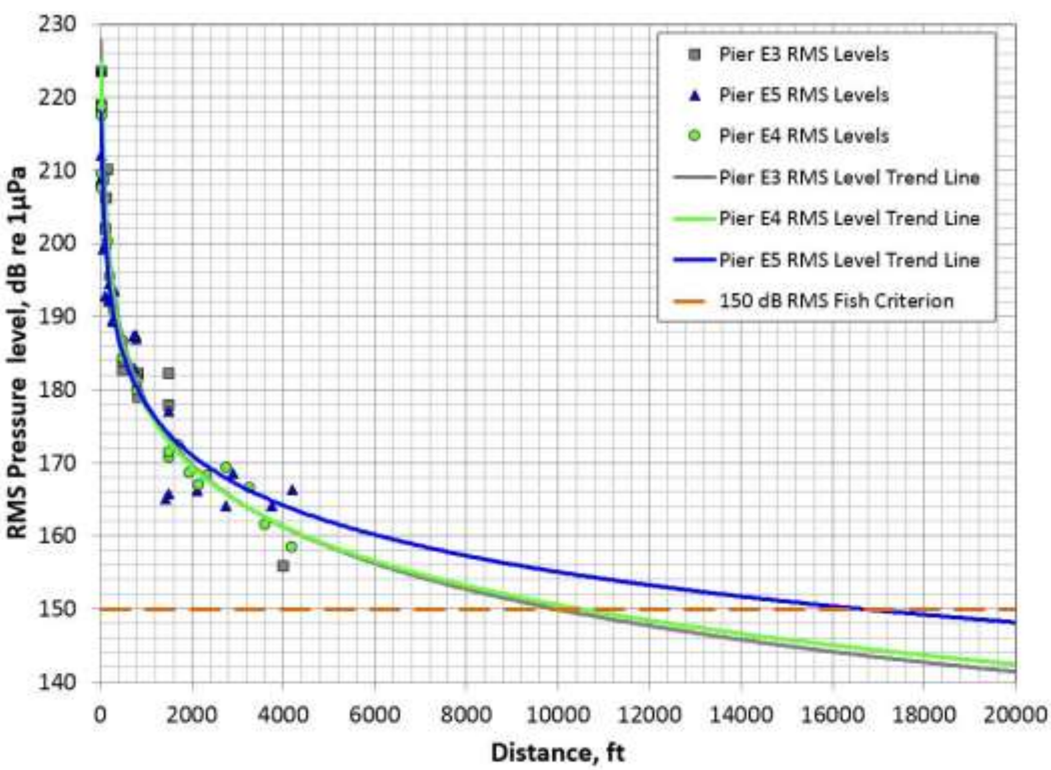


Figure 6-8. RMS Trend Lines for Piers E3, E4, and E5

The estimated distances to the peak, cSEL, and RMS level criteria are shown in Table 6-5 for each of the piers, as well as for the combined data trend line.

Table 6-5. Summary of the Estimated Distances to the Fish Criteria and Thresholds

Criteria/ Threshold	Threshold	Estimated Distance to Thresholds (feet)		
		Pier E3	Pier E4	Pier E5
Overpressure	206 dBp	1,165	642	527
Cumulative SEL, ≥ 2 grams	187 dBe	889	720	620
Cumulative SEL, < 2 grams	183 dBe	1,230	1,012	927
RMS Sound Pressure Level	150 dB	9,942	10,487	16,624

6.2.6. Results Compared to Marine Mammal Criteria

Weighting factors for seals (*Phocidae*), sea lions (*Otariidae*), and porpoises (high frequency [HF] Cetaceans) were subtracted from the measured cSEL values for each pier and were compared to the established marine mammal criteria for the respective mammal groups. The results calculated for each pier are shown in Figure 6-9 for seals, in Figure 6-10 for sea lions, and in Figure 6-11 for porpoises. For Piers E4 and E5, the trend lines for all species fall below the Pier E3 trend line at distances within 3,500 feet of the implosion. At distances beyond 3,500 feet, the trend line for Pier E5 is higher than all the others, but is well below impact criteria at that distance. The effect of marine mammal weightings lowers the cSEL values, compared to the unweighted values. This effect is relatively small for seals and sea lions (approximately 2 to 2.5 dBe at 1,000 feet) and larger (approximately 17 dBe at 1,000 feet) for porpoises. The weightings for the marine mammal increase with distance because the spectral content moves to lower frequency with distance, resulting in fall-off rates that are slightly greater than the unweighted cSEL fall-off rates; the weighting effects the results more dramatically at greater distances, where mostly low frequency energy would be expected.

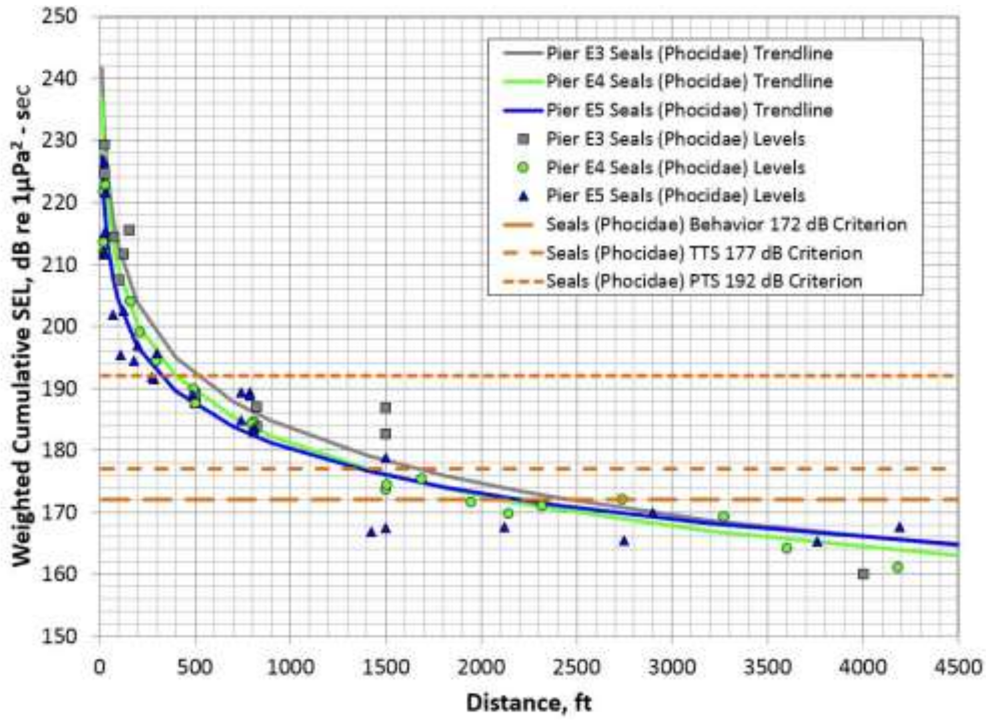


Figure 6-9. Marine Mammal Weighted Measured Levels for Seals (*Phocidae*)

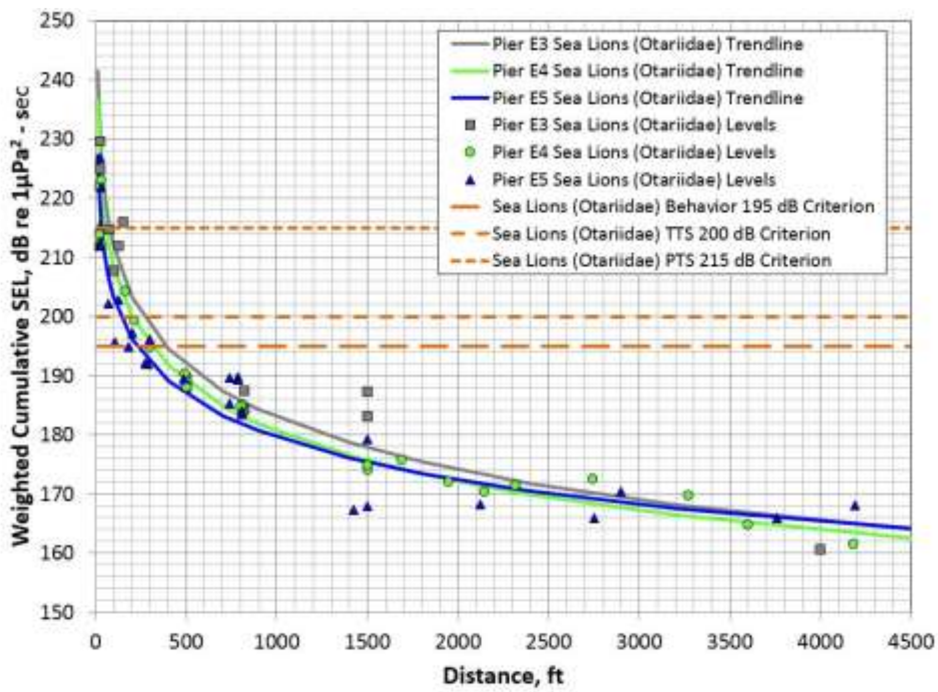


Figure 6-10. Marine Mammal Weighted Measured Levels for Sea Lions (*Otariidae*)

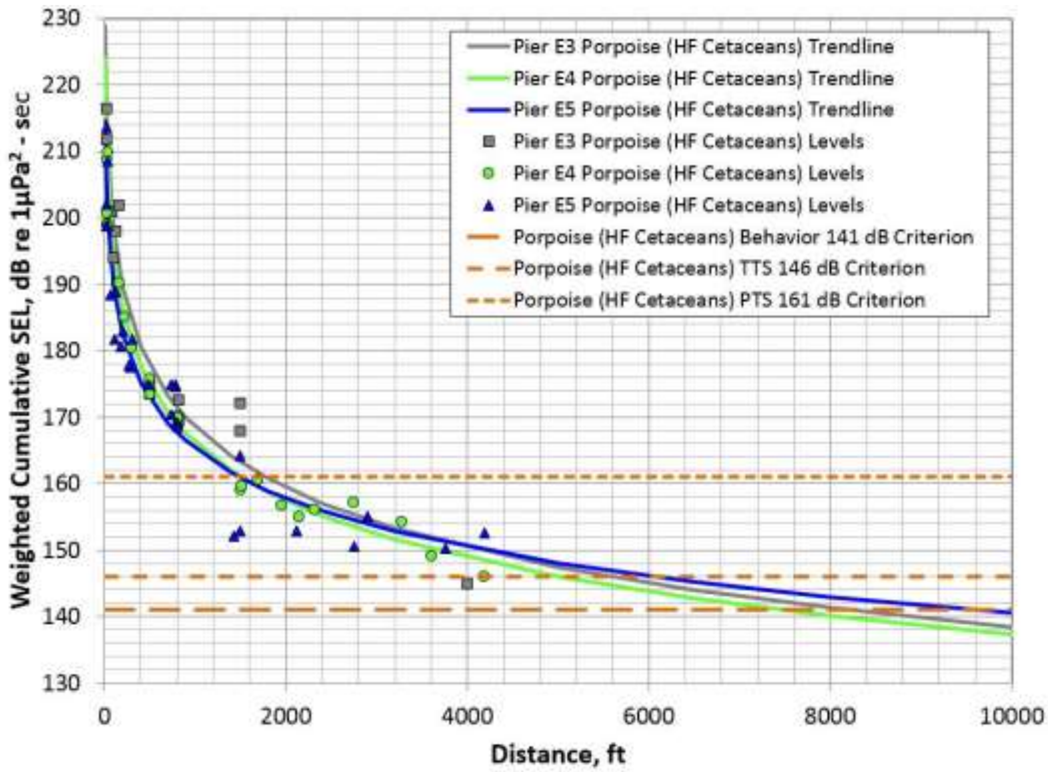


Figure 6-11. Marine Mammal Weighted Measured Levels for Porpoises (HF Cetaceans)

For all marine mammal species, the same criterion level for gastrointestinal (GI) tract injury, lung injury and mortality damage applies. The criteria for a harbor seal were used for all marine mammals, because these are the most abundant marine mammal species in the project area. The overpressure levels measured during each implosion (shown in Figure 6-6) are compared to the GI criterion. For all measurement locations outside the BAS for each pier implosion, the measured peaks were below the criteria. The results of the impulse pressure calculations for each pier are shown in Figure 6-12 and are compared to the lung injury and mortality damage criteria.

Table 6-6 summarizes the distances to all marine mammal thresholds from Pier E3, based on the measurements for the implosion event. Because the distance to the cSEL threshold always was greater than to the L_{peak} threshold for behavior, Temporary Threshold Shift (TTS), and Permanent Threshold Shift (PTS), only the distances to cSEL criteria are shown in Table 6-6.

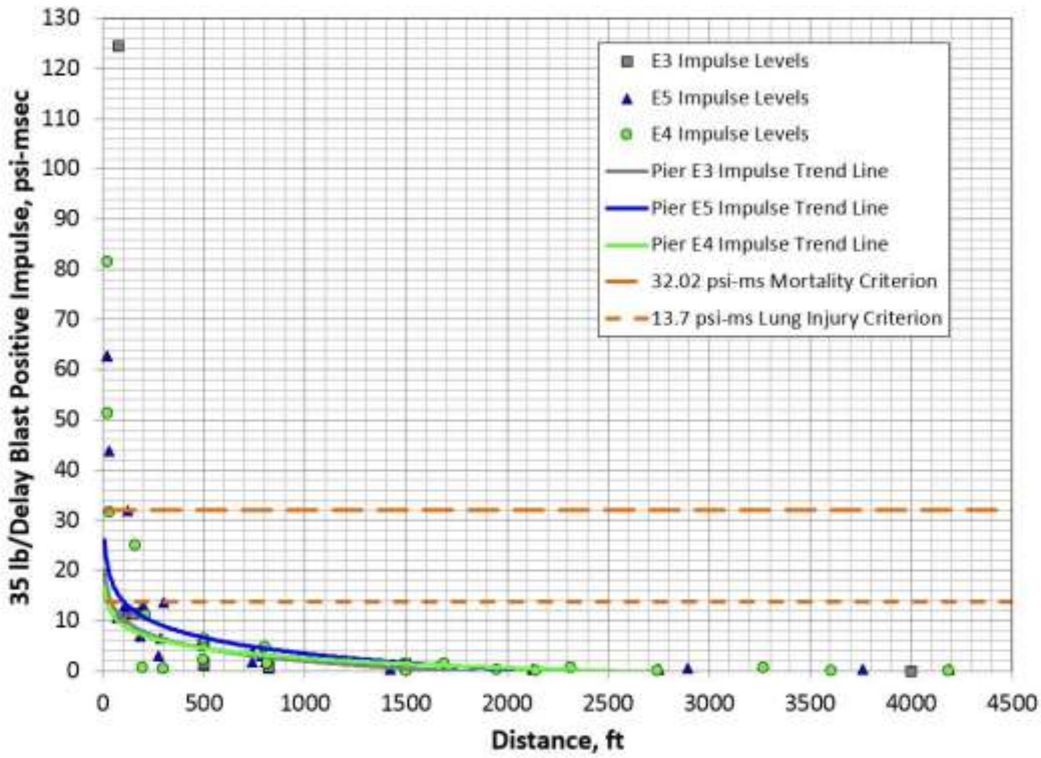


Figure 6-12. Summary of Impulse Results Compared to the Marine Mammal Criteria for Lung Injury and Mortality Damage

6.3. Marine Mammal Monitoring

The Marine Mammal Monitoring Program (MMMP), part of the 2016 Biological Monitoring Plan (Department 2016a) and prepared under the 2016 IHA, was implemented to minimize injury and harassment to marine mammals, establish injury and harassment threshold criteria zones, and specify methods for monitoring and reporting marine mammal activity near the implosion area.

The 2016 IHA allows the occurrence of incidental take of species, including Pacific harbor seal, California sea lion, northern elephant seal, harbor porpoise, northern fur seal, and bottlenose dolphin by Level B Harassment—Behavioral Response as well as TTS in the quantities shown in Table 6-7. Take of marine mammals by Level A Harassment—PTS, injury, or mortality—is prohibited.

Table 6-6. Summary of the Estimated Distances Compared to the Marine Mammal Criteria

Pacific Harbor and Northern Elephant Seal *(Phocidae)*				
		Estimated Distance to Thresholds(feet)		
Criteria	**Threshold**	**Pier E3**	**Pier E4**	**Pier E5**
Behavior	172 dB	2,460	2,110	2,197
TTS	177 dB	1,658	1,395	1,352
PTS	192 dB	507	403	315
GI Tract	237 dB	< 100	< 100	< 100
Lung Injury	13.7 psi-ms	< 100	< 100	106
Mortality	32.02 psi-ms	< 100	< 100	< 100
Sea Lions (Otariidae)				
		Estimated Distance to Thresholds (feet)		
Criteria	**Threshold**	**Pier E3**	**Pier E4**	**Pier E5**
Behavior	195 dB	387	304	225
TTS	200 dB	261	202	139
PTS	215 dB	80	59	33
GI Tract	237 dB	< 100	< 100	< 100
Lung Injury	13.7 psi-ms	< 100	< 100	106
Mortality	32.02 psi-ms	< 100	< 100	< 100
Porpoises (High Frequency Cetaceans)				
		Estimated Distance to Thresholds (feet)		
Criteria	**Threshold**	**Pier E3**	**Pier E4**	**Pier E5**
Behavior	141 dB	8,171	7,446	9,564
TTS	146 dB	5,580	4,998	6,004
PTS	161 dB	1,777	1,511	1,486
GI Tract	237 dB	< 100	< 100	< 100
Lung Injury	13.7 psi-ms	< 100	< 100	106
Mortality	32.02 psi-ms	< 100	< 100	< 100

Table 6-7. Marine Mammal Take Allowed under the 2016 Incidental Harassment Authorization

Species	Level B Take	
	Behavioral	Temporary Threshold Shift
Pacific harbor seal	12	6
California sea lion	3	1
Northern elephant seal	2	1
Harbor porpoise	6	3
Bottlenose dolphin	2	2
Northern fur seal	1	1
Source: Federal Register 2016		

6.3.1. Monitoring Methods

The 2016 IHA prescribes marine mammal monitoring requirements to be implemented before, during, and after underwater blasting activities. The goals of monitoring are to avoid Level A take of marine mammals, document Level B take within authorized take limits, and document any disturbance, harassment, or injury of marine mammals.

6.3.1.1. Marine Mammal In-Water Noise Criteria

In 2013, NMFS established interim sound threshold criteria for take of marine mammals from underwater blasting (Table 6-8). Measured distances to marine mammal threshold criteria from the 2015 test blast and the implosion of Pier E3 were used to conservatively estimate the distances to these threshold criteria for the 2016 test blasts and the implosions of Piers E4 and E5.

6.3.1.2. Test Blast

The distances to Level B TTS monitoring zones for marine mammals during the release of the test charges at Pier E5 were estimated based on the November 5, 2015 Pier E3 test blasts. All distances were extremely close to the pier and fell within or inside the extent of the BAS. Although marine mammals were unlikely to be present within or inside the extent of the BAS, exclusion zones and marine mammal monitoring were implemented. To avoid Level B TTS or greater exposures to marine mammals, a pinniped exclusion zone was established at a distance of 9 feet, and a harbor porpoise and bottlenose dolphin exclusion zone was established at distance of 48 feet from the blasts.

Table 6-8. Intermit Sound Threshold Criteria for Take of Marine Mammals from Underwater Blasting

Group	Species	Behavior		Slight Injury				Mortality
		Behavioral (for ≥ 2 pulses/ 24 hours)	TTS	PTS	Gastro Intestinal Tract	Lung		
Low-frequency Cetaceans	humpback whale	167 dB cSEL (LF_{II})	172 dB cSEL (LF_{II}) or 224 dB peak SPL	187 dB cSEL (LF_{II}) or 230 dB peak SPL	237 dB SPL or 104 psi	39.1 $M^{1/3}$ $(1+[D_{Rm}/10.081])^{1/2}$ Pa-sec Where: M = mass of the animals in kg D_{Rm} = depth of the receiver (animal) in meters		91.4 $M^{1/3}$ $(1+[D_{Rm}/10.081])^{1/2}$ Pa-sec Where: M = mass of the animals in kg D_{Rm} = depth of the receiver (animal) in meters
Mid-frequency Cetaceans	bottlenose dolphin	167 dB cSEL (MF_{II})	172 dB cSEL (MF_{II}) or 224 dB peak SPL	187 dB cSEL (MF_{II}) or 230 dB peak SPL				
High-frequency Cetaceans	harbor porpoises	141 dB cSEL (HF_{II})	146 dB cSEL (HF_{II}) or 195 dB peak SPL	161 dB cSEL (HF_{II}) or 201 dB peak SPL				
Pinnipeds - Phocidae	harbor seal and elephant seal	172 dB cSEL (P_{WI})	177 dB cSEL (P_{WI}) or 212 dB peak SPL	192 dB cSEL (P_{WI}) or 218 dB peak SPL				
Pinnipeds - Otariidae	sea lions and northern fur seal	195 dB cSEL (O_{WI})	200 dB cSEL (O_{WI}) or 212 dB peak SPL	215 dB cSEL (O_{WI}) or 218 dB peak SPL				

Notes:

All decibels are referenced to 1 micro Pascal (re: 1µPa).

dB = decibel(s); cSEL = cumulative sound exposure level; PTS = Permanent Threshold Shift; RMS = root mean square; SPL = sound pressure level; TTS = Temporary Threshold Shift

Source: Finneran and Jenkins 2012

Three NMFS-approved marine mammal observers (MMOs) conducted monitoring before, during, and after the test blasts at Pier E5. The Lead MMO (MMO 1) was on the new East Span bike path, 500 feet north of Pier E5. MMO 2 also was on the bike path, 500 feet west of the Lead MMO, and MMO 3 was on a barge 500 feet west of Pier E5.

6.3.1.3. Pier E5 and Pier e4 Implosion

Before the implosion of Piers E5 and E4, marine mammal Level A exclusion zones and Level B TTS and behavioral monitoring zones were established, based on the requirements of the IHA. The distances to these zones were determined conservatively, based on measured distances to marine mammal threshold criteria from the 2015 implosion of Pier E3.

6.3.1.4. Exclusion Zones

Before the implosions of Piers E4 and E5, a 507-foot pinniped and dolphin exclusion zone (see footnote in Table 6-9, and Figures 6-13 and 6-14), and a 1,777-foot harbor porpoise exclusion zone were established (Table 6-9, and Figures 6-15 and 6-16). The Marine Mammal Exclusion Zones (MMEZs) included all areas where the underwater SPLs or SELs were anticipated to equal or exceed the Level A PTS threshold.

The Pier E3 Demonstration Project used modeled distances to establish the MMEZs based on the thresholds provided by NMFS (shown in Table 6-9) and were highly conservative. Based on the actual hydroacoustics results from the Pier E3 implosion, the distances to the threshold criteria were considerably smaller. The MMEZs for Piers E4 and E5 were based on the measured results from Pier E3, which were conservative because the blast times and total charge weights for each pier implosion were less than those for the Pier E3 implosion. Table 6-9 shows the original estimated distances to the thresholds for Pier E3 and the resulting distances established for Piers E4 and E5, based on the Pier E3 hydroacoustics results. The distances to the thresholds that are listed in Table 6-10 are those used to monitor during the implosions. As outlined in Section 6.2 above, hydroacoustics results from the Pier E4 and E5 implosions, show that the distances to the thresholds for both piers ultimately were smaller than what was monitored during the implosions, indicating a smaller zone of impact.

Table 6-9. Estimated Distances to the Monitored Marine Mammal Criteria

Pinnipeds *(Phocids* and *Otariids)* and Dolphins[1]				
Criteria	Threshold	Estimated Distance to Thresholds (feet)		
		Pier E3	Pier E4	Pier E5
Level B Behavior	172 dB	2,460	2,110	2,197
Level B TTS	177 dB	1,658	1,395	1,352
Level A PTS	192 dB	507	403	315
Porpoises (High Frequency Cetaceans)				
Criteria	**Threshold**	**Estimated Distance to Thresholds (feet)**		
		Pier E3	**Pier E4**	**Pier E5**
Level B Behavior	141 dB	8,171	7,446	9,564
Level B TTS	146 dB	5,580	4,998	6,004
Level A PTS	161 dB	1,777	1,511	1,486

Note:

1. The distances to the Level A and Level B threshold criteria for oteriids (sea lion and fur seal) and the mid-frequency cetacean (bottlenose dolphin) are less than the distance to the phocids (harbor seal and elephant seal) threshold criteria. As the exclusion zones for oteriids and bottlenose dolphin would be in the near-field of the implosion and to simplify monitoring procedures, the Department elected to monitor a larger exclusion zone and Level B harassment monitoring zone for oteriids and bottlenose dolphin.

Figures 6-13 through 6-16 show MMEZs and Level B monitoring zones centered on Piers E4 and E5, using the MMEZs established using the Pier E3 Demonstration Project results.

6.3.1.5. TTS MONITORING ZONES

A 1,658-foot Level B TTS monitoring zone was established for pinnipeds and dolphins (see footnote in Table 6-10 and Figure 6-13), and a 5,580-foot Level B TTS monitoring zone was established for harbor porpoise (Table 6-10 and Figure 6-14).

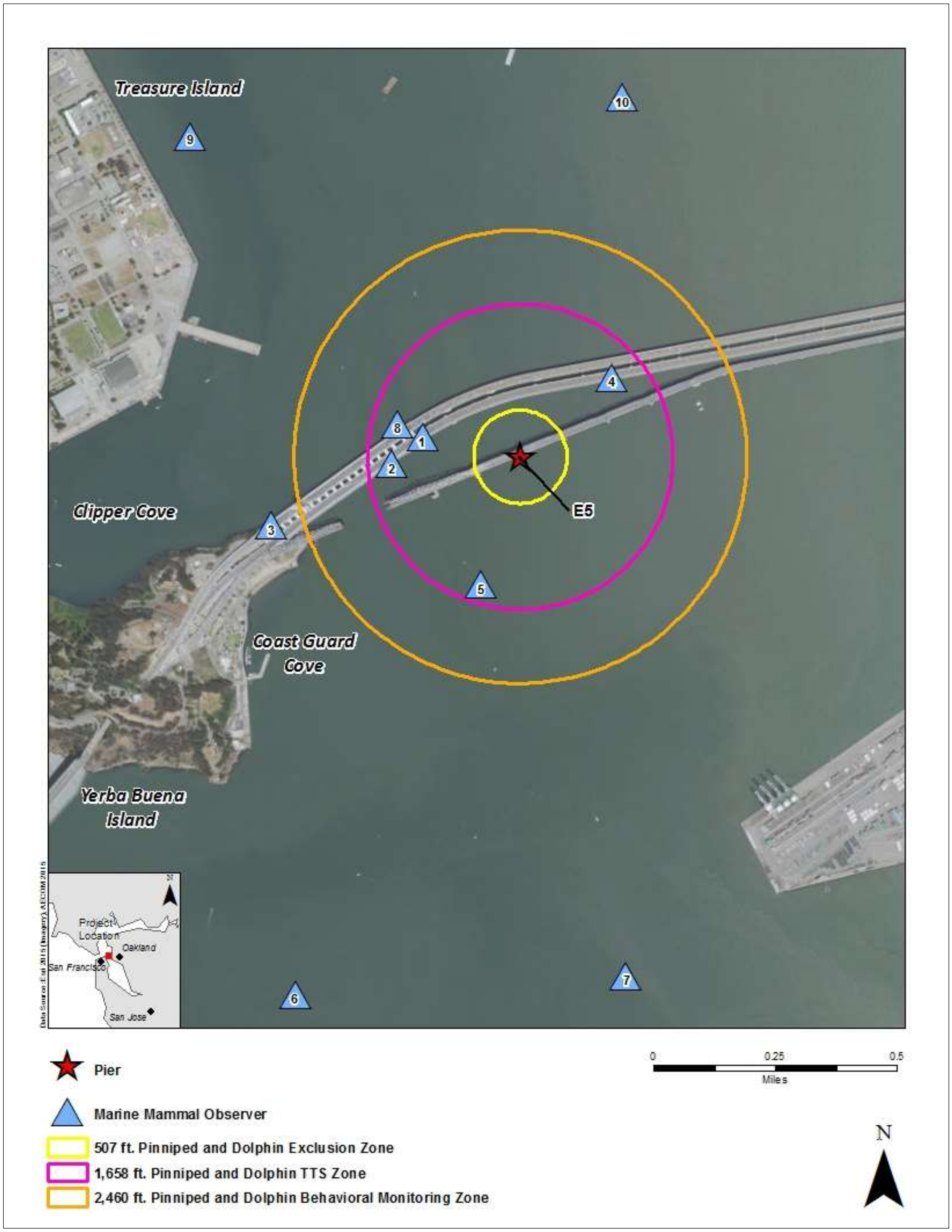


Figure 6-13. Pier E5 Pinniped and Dolphin Exclusion and Behavioral Monitoring Zones

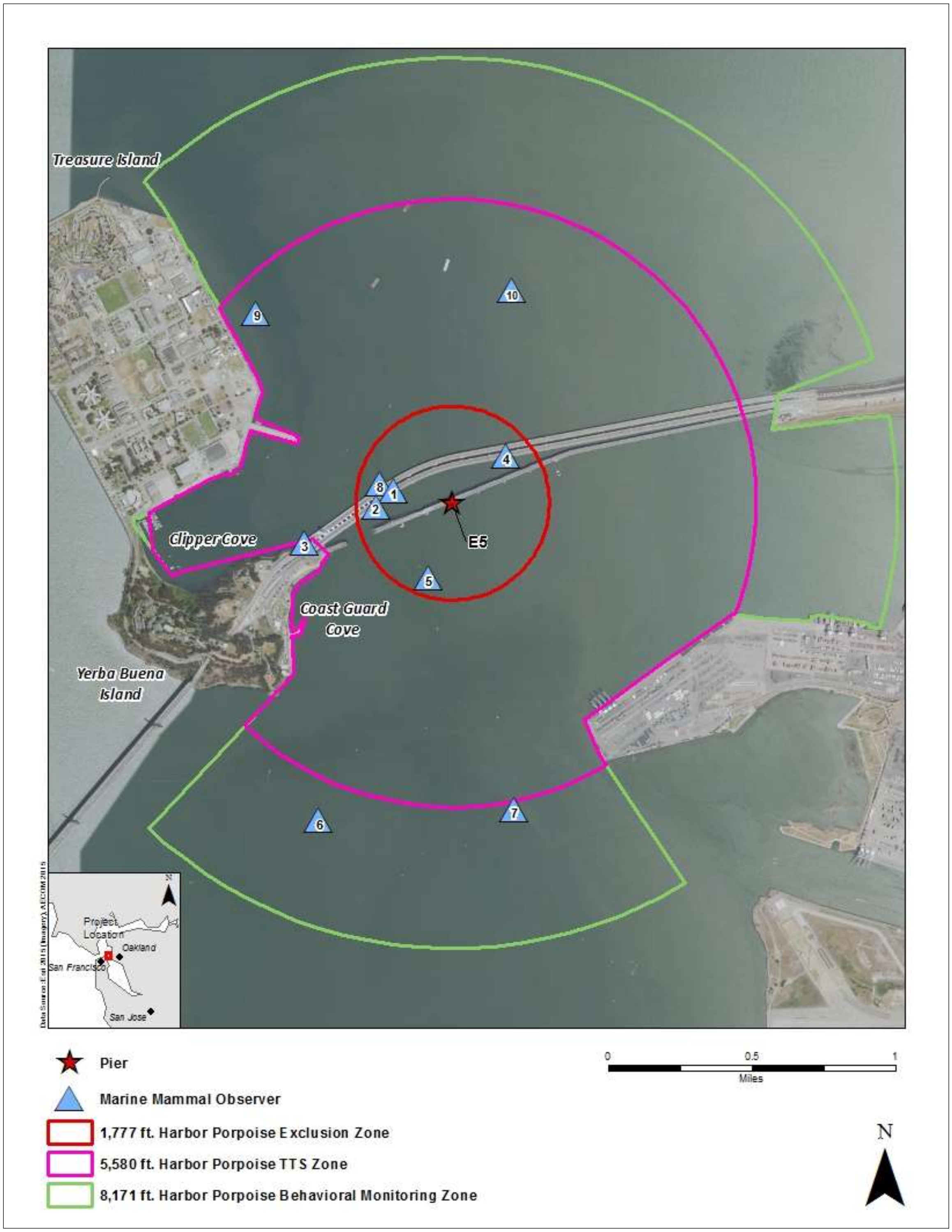


Figure 6-14. Pier E5 Harbor Porpoise Exclusion and Behavioral Monitoring Zones

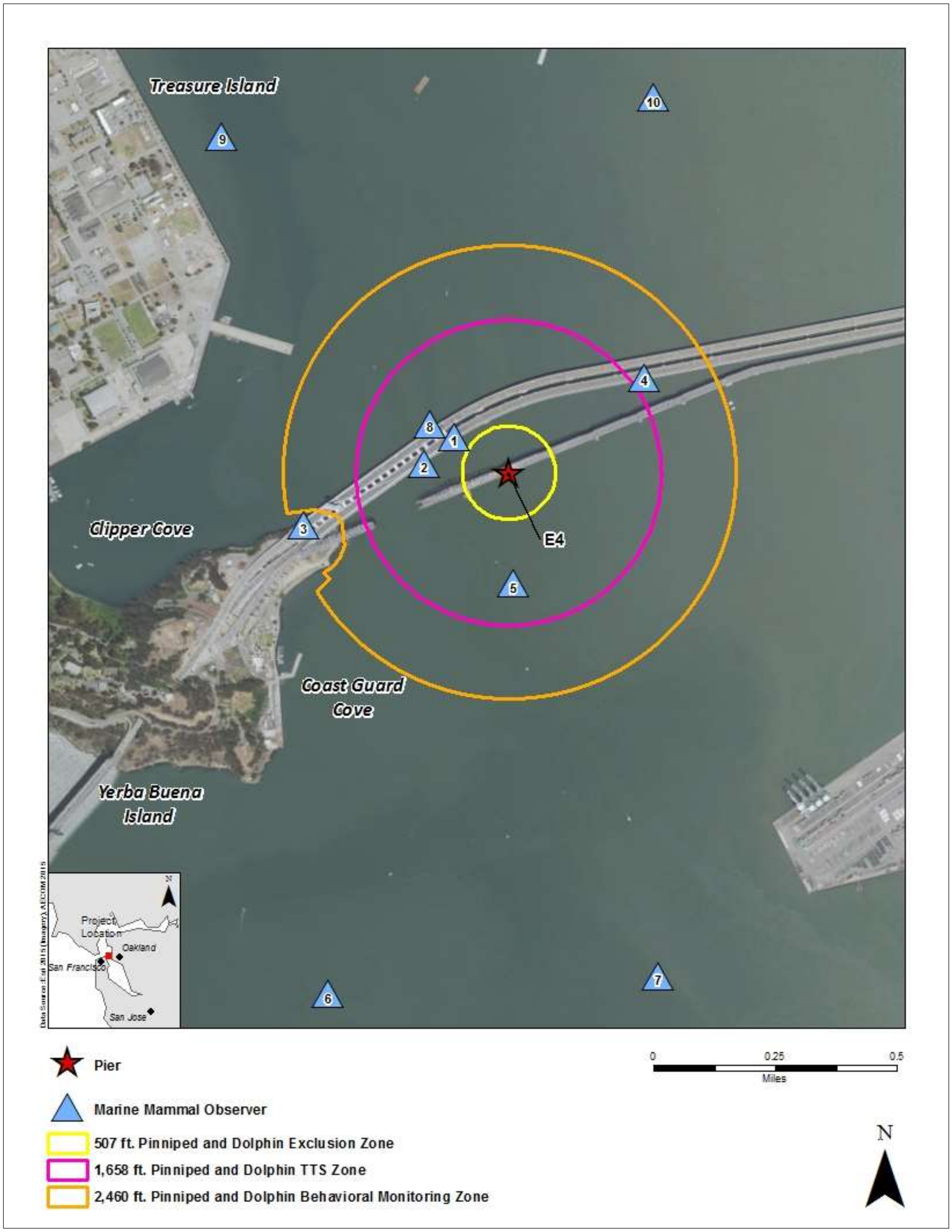


Figure 6-15. Pier E4 Pinniped and Dolphin Exclusion and Behavioral Monitoring Zones

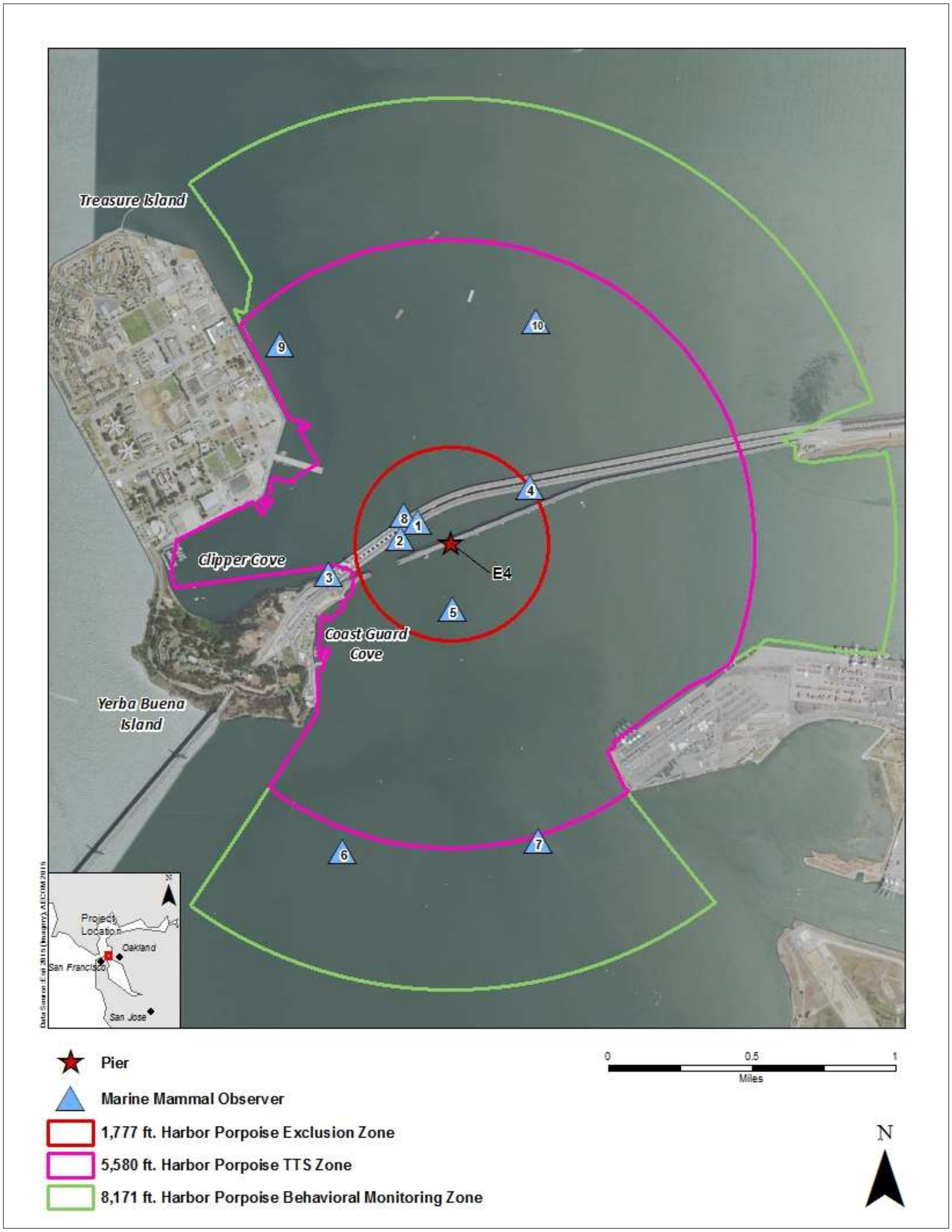


Figure 6-16. Pier E4 Harbor Porpoise Exclusion and Behavioral Monitoring Zones

6.3.1.6. BEHAVIORAL MONITORING ZONES

A 2,460-foot Level B behavioral monitoring zone was established for pinnipeds and dolphins (Table 6-10, and Figures 6-13 and 6-15). An 8,171-foot Level B behavioral monitoring zone was established for harbor porpoise (Table 6-10 and Figure 6-14 and Figure 6-16). Figures 6-13 through 6-16 show MMEZs and Level B behavioral monitoring zones centered on Piers E4 and E5.

Table 6-10. Exclusion and Monitoring Zones

Species	Level A Exclusion Zone (feet)	Level B Monitoring Zones: Temporary Threshold Shift (feet)	Level B Monitoring Zones: Behavioral Response (feet)
Pinnipeds and Dolphins (harbor seal, sea lion, elephant seal, fur seal and bottlenose dolphin)	507	1,658	2,460
Harbor porpoise	1,777	5,580	8,171

Notes:

Exclusion and monitoring zones are based on measured distances to threshold criteria for phocids (harbor seal and elephant seal) and high-frequency cetaceans (harbor porpoise) from the implosion of Pier E3 (Department 2015b).

The distances to the Level A and Level B threshold criteria for oteriids (sea lion and fur seal) and the mid-frequency cetacean (bottlenose dolphin) are less than the distance to the phocids (harbor seal and elephant seal) threshold criteria. As the exclusion zones for oteriids and bottlenose dolphin would be in the near-field of the implosion and to simplify monitoring procedures, the Department elected to monitor a larger exclusion zone and Level B harassment monitoring zone for oteriids and bottlenose dolphin.

Source: Federal Register 2016

6.3.1.7. MARINE MAMMAL MONITORING

Ten NMFS-approved MMOs conducted monitoring before, during, and after the implosion of Piers E4 and E5. MMOs were positioned near the edge of each of the pinniped and dolphin monitoring zones and within the larger harbor porpoise monitoring zones, using boats, bridge piers, and the new SFOBB, as well as sites on YBI and TI. The locations for MMOs are shown in Figures 6-13 through 6-16.

Each MMO recorded the observation position, start and end times of observations, and weather conditions (e.g., sunny/cloudy, wind speed, fog, visibility). For each marine mammal sighting, the following items were recorded, if possible:

- Species, number of animals (i.e., include with or without a dependent pup/calf);
- Age class (i.e., pup/calf, juvenile, adult);
- Identifying marks or color (e.g., scars, red pelage, damaged dorsal fin);

- Position relative to the pier (i.e., distance and direction);
- Movement (i.e., direction and relative speed);
- Behavior (e.g., logging [resting at the surface], swimming, spy-hopping [raising above the water surface to view the area], foraging);
- Signs of injury, stress, or other unusual behavior; and
- Duration of sighting or times of multiple sightings of the same individual.

All MMOs were equipped with radios, using a dedicated marine mammal monitoring channel with mobile phones as a back-up (Figure 6-17).

Figure 6-17. Biological Monitor on New San Francisco–Oakland Bay Bridge

One MMO, designated as the Lead MMO, was in constant contact with the Lead Biological Monitor, who was with the Department’s Resident Engineer and Blaster-in-Charge. The Lead MMO coordinated marine mammal sightings with the other MMOs. Each MMO contacted the other MMOs when a sighting was made within or near the MMEZs, so that the MMOs within overlapping areas of responsibility could continue to track the animal and the Lead MMO was aware of the animal’s position. If the sighting was within 30 minutes of the scheduled blasting and an animal had entered the MMEZs or was near it, the Lead MMO would notify the Lead Biological Monitor. The Lead MMO kept everyone informed of the location and disposition of the animal, and notified the Lead Biological Monitor that the MMEZs were clear before the implosion.

6.3.2. Monitoring Results

6.3.2.1. Pier E5 Test Blast Results

The Pier E5 test blasts occurred on October 7, 2016, at 11:10 a.m. and 11:47 a.m. Marine mammal monitoring was conducted from 9:45 a.m. to 1 p.m. A total of 15 harbor seals were observed during the monitoring period on October 7, 2016.

6.3.2.2. Pier E5 Implosion Results

The implosion of Pier E5 occurred on October 15, 2016, at 11:57 a.m., and marine mammal monitoring was conducted from 9:45 a.m. to 1:00 a.m. A total of 31 harbor seals were observed during the monitoring period. Seventeen harbor seals were observed in Coast Guard Cove or Clipper Cove, outside the Level B behavioral monitoring zone. Fourteen harbor seals were observed within the Level B TTS or behavioral monitoring zones during pre-implosion monitoring. Two harbor seals were within the Level B behavioral monitoring zone during the implosion:

No animals were observed within the Level B TTS monitoring zone during the implosion. No animals were observed within the Level A exclusion zone during the monitoring period. Thus, the Pier E5 implosion resulted in the take of two harbor seals by Level B behavioral harassment.

One humpback whale potentially was observed, 15,000 feet north of Pier 5, 18 minutes before the implosion. Based on measured SPLs from the Pier E5 implosion, the distance to the 167 dBe cSEL behavioral response threshold for low-frequency cetaceans was 4,300 feet. At a distance of 15,000 feet, the humpback whale was not exposed to an SPL that equaled or exceeded the threshold criteria for behavioral harassment. Because of the distance, high winds, and lack of other corroborating whale sighting reports, this sighting could not be confirmed.

6.3.2.3. Pier E4 Implosion Results

The Pier E4 implosion occurred on October 29, 2016, at 11:23 a.m. Marine mammal monitoring was conducted from 9 a.m. to 12 p.m. on October 29, 2016. At total of 21 harbor seals and one sea lion were observed during the monitoring period. Eleven harbor seals were observed in Coast Guard Cove or Clipper Cove, outside the Level B behavioral monitoring zone. Ten harbor seals were observed within the Level A exclusion zone, Level B TTS, or behavioral monitoring zones during pre-implosion monitoring.

At 11:08 a.m., an adult harbor seal with a light coat (silver with black spots) was observed within the Exclusion Zone, 450 feet northeast of Pier E4. The seal was slowly swimming south at the surface for about 20 seconds before diving. No other observations were made within the Exclusion Zone.

At 11:20 a.m., an adult harbor seal with a light coat (silver with black spots) was observed within the Behavioral Response Zone, 2,000 feet southeast of Pier E4., and was swimming south. The 11:20 a.m. seal was observed along the same course as the seal observed at 11:08 a.m., and was similar in size and pelage pattern. The 11:08 a.m. and 11:20 a.m. observations likely were of the same seal, but the MMOs could not confirm because of the time and distance between the two sightings. Therefore, as a conservative measure, the Pier E4 implosion was delayed until approximately 15 minutes had elapsed from the first observation at 11:08 a.m.

A harbor seal will swim approximately 2.8 to 4.6 feet per second. Thus, in the 12 minutes from the first observation, the seal could have traveled between 2,000 and 3,300 feet, which would have placed the seal within the area of the 11:20 a.m. observation. The 11:20 a.m. observation was approximately 2,400 feet south of the 11:08 a.m. observation.

A different harbor seal was observed within the Level B TTS zone immediately before the implosion and during the implosion, and one sea lion was observed within the Level B behavioral monitoring zone during the Pier E4 implosion. No delays resulted from these two sightings.

No other marine mammals were observed during the monitoring period. Table 6-11 and Table 6-12 summarize all marine mammal sightings during monitoring for the implosions of Piers E4 and E5, respectively. Highlighted cells in Table 6-11 and Table 6-12 indicate marine mammals that were within the Level B Behavioral Harassment Zone at the time of implosion.

Table 6-11. Summary of Marine Mammal Sightings during Monitoring for the October 15, 2016 Pier E5 implosion

Times	Species	Distance/Direction from Pier E5	Surface or Travel Direction	Time Pre- or Post-Blast	Notes
09:45 Observations Begin					
09:45–13:01	5 Harbor Seals	2,300–3,100 Southwest	Surface	132 minutes pre-implosion—64 minutes post-implosion	The seals likely were foraging in Coast Guard Cove outside the Behavioral Response Zone.
09:50–10:54	Harbor Seal	1,000 feet northeast	Surface	63–127 minutes pre-implosion	The seal likely was foraging around the new SFOBB Pier E5.
09:50–11:27	Harbor Seal	1,200 feet northeast	Surface	30–127 minutes pre-implosion	The seal likely was foraging around the new SFOBB Pier E5.
10:00	Harbor Seals	5,500 feet	Southwest	117 minutes pre-implosion	Outside the Behavioral Response Zone
10:00–11:27	4 Harbor Seals	550–1,000 feet	Swimming north and northeast	30–117 minutes pre-implosion	The seals likely were foraging around Piers E3 and E4 of new SFOBB.
10:13	Harbor Seal	2,100 feet southwest	Swimming north	52 minutes pre first blast	Near old SFOBB Pier E7
10:18	Harbor Seal	1,000 feet east	Surface	99 minutes pre-implosion	Near old SFOBB Pier E7
10:25–10:35	Harbor Seal	5,000 feet northwest	Surface	82–92 minutes pre-implosion	Outside the Behavioral Response Zone
10:27–10:38	Harbor Seal	5,000 feet south	Surface	79–90 minutes pre-implosion	Outside the Behavioral Response Zone
10:33–10:45	Harbor Seal	2,500 feet north	Surface	72–84 minutes pre-implosion	At the northern edge of the Behavioral Response Zone
10:48–10:56	Harbor Seal	2,900 feet northwest	Surface	61–69 minutes pre-implosion	Outside the Behavioral Response Zone near Treasure Island pier
10:59–11:14	Harbor Seal	3,700 feet northwest	Surface	43–58 minutes pre-implosion	Outside the Behavioral Response Zone
11:00–11:01	Harbor Seal	1,700 feet south	Swimming east	56–57 minutes pre-implosion	Within the Behavioral Response Zone
11:14	Harbor Seal	3,800 feet north	Surface	43 minutes pre-implosion	North of the Behavioral Response Zone
11:20–11:26	Harbor Seal	3,000–5,000 feet west	Surface	31–37 minutes pre-implosion	The seals likely were foraging in Clipper Cove outside the Behavioral Response Zone.

Times	Species	Distance/Direction from Pier E5	Surface or Travel Direction	Time Pre- or Post-Blast	Notes
11:24–11:40	2 Harbor Seals	4,700 feet northwest	Swimming south	17–33 minutes pre-implosion	Outside the Behavioral Response Zone
11:39	Humpback Whale	15,000 feet north	Surface	18 minutes pre-implosion	Outside the Behavioral Response Zone and species could not be verified.
11:44–11:57*	Harbor Seal	1,900 feet south	Surface	0–13 minutes pre-implosion	The seal was within the Behavioral Response Zone at time of implosion; the seal dove when implosion occurred and was not seen again.
11:47	Harbor Seal	7,500 feet northeast	Surface	10 minutes pre-implosion	Outside the Behavioral Response Zone
11:47–12:04*	Harbor Seal	1,300–2,000 feet south	Swimming east	10 minutes pre-implosion to 7 minutes post-implosion	The seal was within the Behavioral Response Zone at the time of the implosion.
11:49–11:52	Harbor Seal	2,900 feet northwest	Swimming northwest	5–8 minutes pre-implosion	Outside the Behavioral Response Zone
11:56–12:01	Harbor Seal	2,500–3,000 feet north	Surface	1 minute pre-implosion to 4 minutes post-implosion	Outside the Behavioral Response Zone
11:57 Pier E5 Implosion					
11:57	Harbor Seal	4,100 feet northwest	Surface	During implosion	Outside the Behavioral Response Zone; dove with a splash
12:03–12:12	Harbor Seal	5,000 feet south	Surface	5–15 minutes post-implosion	Outside the Behavioral Response Zone
12:09	Harbor Seal	2,300 feet west	Surface	12 minutes post-implosion	North of the new SFOBB Pier T1
13:00 End of Observations					
Total Harbor Seals Observed: 31					
Number of Seals Exposed to the Implosion Sound within the Behavioral Response Zone (Level B Behavioral take): 2					
Total Seals Observed near the Pier E5 Area (within the TTS or Behavioral Response Zones): 14					
Total Seals Observed in Coast Guard or Clipper Coves, and Outside the Behavioral Response Zone: 17					

Table 6-12. Summary of Marine Mammal Sightings during Monitoring for the October 29, 2016 Pier E4 Implosion

Times	Species	Distance/Direction from Pier E4	Surface or Travel Direction	Time Pre- or Post-Blast	Notes
09:30 Observations Begin					
09:01–10:16	Harbor Seal	5,600 feet southwest	Surface	67–142 minutes pre-implosion	The seal likely was foraging outside the Behavioral Response Zone.
09:19–09:26	Harbor Seal	1,000 feet northeast	Swimming north	117–124 minutes pre-implosion	Swimming north under the new SFOBB, within the TTS zone
09:26	Harbor Seal	400 feet north	Surface	117 minutes pre-implosion	North of Pier E4 in the exclusion zone
10:34–10:36	Harbor Seal	1,500 feet northeast	Swimming east	47–49 minutes pre-implosion	
10:39–10:49	Harbor Seal	450 feet north	Surface	34–44 minutes pre-implosion	North of Pier E4 in the exclusion zone
10:05–10:50	2 Harbor Seals	850 feet northeast	Surface	33–78 minutes pre-implosion	Within the TTS zone
10:15–10:57	Harbor Seal	2,700 feet northwest	Surface	26–68 minutes pre-implosion	Outside the Behavioral Response Zone
10:25–10:36	Harbor Seal	4,500 feet northeast	Swimming south	47–58 minutes pre implosion	Outside the Behavioral Response Zone
10:29	Harbor Seal	6,000 feet northeast	Surface	54 minutes pre-implosion	Outside the Behavioral Response Zone
10:55	Harbor Seal	2,700 feet northwest	Swimming north	28 minutes pre-implosion	Outside the Behavioral Response Zone
10:59–11:02	Harbor Seal	2,200 feet northwest	Swimming north	21–24 minutes pre implosion	Within the Behavioral Response Zone
11:04	Harbor Seal	1,600 feet northeast	Swimming east	19 minutes pre-implosion	Within the TTS zone
11:08	Harbor Seal	450 feet northeast	Swimming south	15 minutes pre-implosion	Within the exclusion zone; implosion delayed for 15 minutes until clear

Times	Species	Distance/Direction from Pier E4	Surface or Travel Direction	Time Pre- or Post-Blast	Notes
11:06–12:16	California Sea Lion	1,700 feet east	Surface	17 minutes pre-implosion to 53 minutes pre-implosion	A sea lion that appeared to be sick/injured (continuously at the surface with labored breathing) was observed before the implosion and did not move during the implosion, within the Behavioral Response Zone.
11:15	Harbor Seal	1,500 feet northeast	Swimming south	8 minutes pre-implosion	Within the TTS zone around Piers E5 and E6 of the new SFOBB
11:23 Pier E4 Implosion					
11:27	Harbor Seal	4,300 feet northwest	Swimming north	4 minutes post-implosion	Outside the Behavioral Response Zone
11:29–11:39	Harbor Seal	3,300 feet west	Swimming south	6–16 minutes post-implosion	Outside the Behavioral Response Zone
11:32–11:58	Harbor Seal	4,000 feet west	Surface	8–34 minutes post-implosion	Foraging in Clipper Cove, outside the Behavioral Response Zone
11:34–11:39	Harbor Seal	4,000 feet north	Surface	11–16 minutes post-implosion	Outside the Behavioral Response Zone
11:46	2 Harbor Seals	2,000 feet south	Swimming southwest	23 minutes post-implosion	Within the Behavioral Response Zone
11:53	Harbor Seal	3,500 feet north	Surface	30 minutes post-implosion	Outside the Behavioral Response Zone
12:18	Harbor Seal	3,200 feet west	Swimming south	55 minutes post-implosion	Outside the Behavioral Response Zone
Total Harbor Seals Observed: 21; and one California sea lion					
Number of Seals Exposed to the Implosion Sound within the Behavioral Response Zone (Level B Behavioral Take): one sea lion					
Number of Seals Exposed to the Implosion Sound within the TTS Zone (Level B Behavioral Take): one harbor seal					
Total Seals Observed near the Pier E5 Area (within the TTS or Behavioral Response Zones): 10					
Total Seals Observed Outside the Behavioral Response Zone (includes within Coast Guard or Clipper Coves): 11					

6.3.2.4. STRANDING SURVEY

A stranding plan was prepared in cooperation with the NMFS-designated marine mammal stranding, rescue, and rehabilitation center for central California. Although avoidance and minimization measures were anticipated to prevent any injuries from the implosion, preparations were made in the unlikely event that marine mammals were injured. Because sick, injured, or dead marine mammals could strand in the Bay for various reasons unrelated to the implosion activities, it was necessary to determine thecause of stranding for any marine mammals that appeared within 3 days after the implosion. Therefore, plans were made to examine sick or injured individuals observed after the implosion more thoroughly, to determine the cause of the stranding.

A Marine Mammal Center stranding team member and a veterinarian were staged near the project site at the time of the implosions, to quickly recover any injured marine mammals, provide emergency veterinary care, stabilize the animal’s condition, and transport individuals to the stranding facility. Plans were made to notify NMFS (both the regional office and headquarters) immediately if any injured or dead animals were found, even if the animal appeared to be sick or injured from a cause other than the implosion.

Post-implosion stranding surveys were conducted immediately after the Pier E5 implosion event on October 15, 2016, and over the following 3 days (October 16, 17, and 18) to identify any injured or deceased marine mammals. Stranding surveys for the implosion of Pier E4 were conducted on October 29, 30, 31 and November 1, 2016, and used the same procedures as those implemented for the implosion of Pier E5. The surveys were conducted by the Lead MMO; the Marine Mammal Center stranding team was not present during the surveys. The surveys were conducted along the new and old SFOBB, and around YBI and TI, the Oakland outer harbor, and the shallows between the SFOBB and Emeryville.

No stranded marine mammals were discovered in the water or along any of the shore areas during the stranding surveys for Piers E4 and E5. No marine mammals were rescued by the Marine Mammal Center in the Central Bay during a 2-week period following each implosion, indicating no marine mammals were observed to have any evidence of blast trauma (Zahniser, pers. comm., 2016). A sick or injured California sea lion juvenile was observed before the Pier E4 implosion, in the Behavioral Response Zone between Piers E7 and E8 of the old SFOBB. The sea lion still was in the same area during and for 45 minutes after the implosion; the stranding team attempted to find that sea lion and assess its health, but it was not located during the survey.

6.4. Avian Monitoring

In 2015, an Avian Monitoring Plan (AMP) was developed as part of the *SFOBB Project Pier E3 Demonstration Project Biological Monitoring Programs* (Department 2015a). The Department's AMP for tests blasts and controlled blasting was designed to ensure that protected avian species would not be affected by harmful sound/pressure waves generated using explosive charges in the Bay. Because of the impedance of sound at the air–water interface, impacts on birds would be limited to any individuals submerged during the implosion.

Since 2015, the AMP has been revised to address the various elements of avian monitoring to be completed for the implosion of Piers E4 to E18. The AMP directs the use of deterrence measures, establishment of a 300-foot Avian Watch Zone, and use of a delay protocol if a listed diving bird enters the Avian Watch Zone immediately before pier implosion.

6.4.1. Avian In-Water Noise Criteria

To evaluate the potential for auditory damage to birds from impulse noise in-water, the Department used the 2014 USFWS and Washington Department of Transportation (WSDOT 2014) criteria for injury to the marbled murrelet resulting from impact pile driving of steel piles. This guidance established a 202-dBe cSEL sound threshold for auditory injury and 208 dBe cSEL for non-auditory injury from underwater noise, as well as a 150-dB RMS for potential behavioral response. These thresholds are summarized in Table 6-13. USFWS considers the 150-dB RMS zone to be a guideline, not a threshold.

Table 6-13. Criteria for Injury to Marbled Murrelets from Underwater Sound Resulting from Impact Pile Driving

Type of Injury	Threshold
Auditory Injury	202 dB cSEL
Non-auditory Injury	208 dB cSEL
Potential Behavioral Response	150 dB RMS
Notes: dB = decibel; cSEL = cumulative sound exposure level; RMS = root-mean-square Source: WSDOT 2014	

The Department proceeded with use of the auditory injury threshold (i.e., 202 dBe cSEL) to avoid impacts on protected diving birds during pier implosion, to maintain consistency with past projects where measures were taken to protect avian species. The 202 dBe cSEL threshold was measured at approximately 300 feet from the pier during the implosion of Pier E3. The Department took the conservative approach of applying the measured distance to the avian auditory injury threshold for Pier E3 to the avian watch zone for Piers E4 and E5. The 300-foot avian watch zone was implemented and monitored to protect special-status diving birds during each controlled blasting event (Figure 6-18). To avoid impacts, the Department used deterrents (i.e., sound cannons) to encourage target avian species to relocate from the 300-foot Avian Watch Zone.

Figure 6-18. Avian Monitoring Locations and Watch Zones for Piers E4 and E5

6.4.2. Monitoring Methods

6.4.2.1. Test Blast

Avian biologists used the monitoring protocol outlined in the Department’s 2016 Biological Monitoring Program, for the two Pier E5 test blasts. A Department biologist monitored for birds immediately before, during, and after each test blast from the bicycle and pedestrian pathway on the new East Span. The avian monitor recorded bird species observed near Pier E5 and noted general behavior. As a precaution, detonation of the test charge would have been delayed by the Lead Biological Monitor if any protected birds were observed diving into or foraging in the water column near Pier E5.

6.4.2.2. Pier E5 and E4 Implosion

Avian monitoring before, during, and after the implosions of Pier E4 and E5 followed the monitoring protocol described in the 2016 Biological Monitoring Program. Three avian biologists monitored the 300-foot Avian Watch Zone and surrounding area for bird activity for at least 30 minutes before the implosions of Piers E4 and E5. One monitor, designated as the Lead Avian Monitor, communicated directly with the Lead Biological Monitor. Two avian biologists, one of whom was the Lead Avian Monitor, were positioned on the bicycle and pedestrian pathway of the new East Span at the approximate location of Pier E3. One avian monitor was positioned at water level on the pier cap of westbound Pier E3 of the new East Span (Figure 6-1). The avian monitors observed and recorded all bird activity within and surrounding the Avian Watch Zone. Avian monitoring began at least 30 minutes before the scheduled start of each implosion and continued, in the form of bird predation monitoring (see Section 6.5.3), for at least 30 minutes after each implosion.

The following data were recorded for each bird observed in the time leading up to the implosion:

- Time;
- Observation location;
- Bird species, number, and age;
- Approximate distance from pier; and
- Bird activity observed (i.e., flying through, foraging from the air, on water, diving, foraging below surface).

In accordance with the 2016 Biological Monitoring Program, if a special-status (i.e., Federal Endangered Species Act, California Endangered Species Act, or California Fish and Game Code-fully protected) diving bird was observed, the avian monitors were to monitor its activity. If the bird was in the air and traveling from the Avian Watch Zone away from the pier, no further action was deemed to be necessary. If a protected bird was observed diving into or foraging in the water column within the 300-foot Avian Watch Zone, the monitor was to communicate this information to the Lead Avian Monitor, who was to relay the message to the Lead Biological Monitor. The Lead Biological Monitor was to be in direct communication with the Resident Engineer and Blaster-in-Charge. Pier implosion was to be delayed until the protected species left the Avian Watch Zone. Departure of an individual bird from the watch zone was to be documented and communicated to the Lead Biological Monitor. If a dead or injured bird was observed after the demolition blast events, the Lead Avian Monitor was to notify the Lead Biological Monitor, who was to contact USFWS and CDFW within 24 hours, compliant with procedures outlined in project authorizations.

Approximately 1 minute before the blasts, the Department used propane-powered sound cannons to discourage birds from occupying the Avian Watch Zone. A sound cannon emits a short, loud shot that can deter birds within a 5-acre diameter from a cannon. The sound cannons were placed on barges approximately 100 feet from the pier and were used to encourage birds to relocate from the 300-foot Avian Watch Zone.

6.4.3. Monitoring Results

6.4.3.1. Test Blast Results

Avian monitoring for the Pier E5 test blasts began at 10:05 a.m. and concluded at 11:50 a.m. on October 7, 2016. The avian monitor was positioned on the bicycle and pedestrian pathway of the new East Span, approximately 700 feet north of Pier E5. The two propane sound cannons, staged on barges flanking Pier E5 at approximately 100 feet, were not fired before the first blast because of technical difficulties. The cannons were fired before the second test blast at 11:19 a.m., 11:21 a.m., and 11:46 a.m. A gull was noted to flush at 11:19 a.m., when the propane sound cannons were successfully deployed.

6.4.3.2. Pier E5 Implosion Results

Avian monitoring for the Pier E5 implosion was conducted from 10 a.m. to 12:50 p.m. on October 15, 2016. Three biologists monitored the 300-foot Avian Watch Zone and surrounding area for bird activity before, during, and after the implosion of Pier E5 (see Figure 6-18). One minute before the blast, the Department fired a remote-controlled sound cannon designed to deter birds from the area, from a barge approximately 100 feet west of Pier E5. The blast occurred at 11:57 a.m. Wind speed over the water picked up significantly after the blast.

No special-status diving birds were recorded within the 300-foot Avian Watch Zone before the blast. The sound canon flushed two gulls from beneath the new East Span; both flew north, away from Pier E5. After the blast, when wind speeds picked up, a relatively low amount of bird activity was observed. Because the blast was conducted at a high tide, outgoing currents after the blast carried floating debris northward, beneath the new East Span. Post-blast observations consisted primarily of western gulls flying over the project area and following the outgoing current, scanning the water, and landing to pursue moribund fish and other floating debris. No injured birds were observed after the implosion.

6.4.3.3. Pier E4 Implosion Results

Avian monitoring for the Pier E4 implosion was conducted from 9:30 a.m. to 12:02 p.m. on October 29, 2016. Three biologists monitored the 300-foot Avian Watch Zone and surrounding area for bird activity before, during, and after the implosion of Pier E4 (see Figure 6-18). At 11:20 a.m., the Department fired a remote-controlled sound cannon designed to deter birds from the area, from a barge approximately 100 feet west of Pier E4. The blast occurred at 11:57 a.m.

No special-status diving birds were present within the 300-foot Avian Watch Zone immediately before the implosion. No double-crested cormorants, terns, or other sea birds were observed predating on injured or dead fish after the implosion. No injured birds were observed after the implosion.

6.5. Fisheries Monitoring

The Fisheries Monitoring Program includes the following: 1) sonar-based surveys before each implosion to assess the presence of fish assemblages; 2) bird predation monitoring conducted immediately after each pier implosion to help assess the level to which fish are affected by the project; and 3) fish salvage to further understand the quantity, species, and nature of injury or mortality to fish. In addition, the Department monitors Pacific herring during debris removal work that occurs during the herring spawning season (December 1 through February 28). The Department received authorization from CDFW and was issued a Pacific Herring Work Waiver to continue in-water work into December 2016.

6.5.1. Fish Assemblage

As a condition of the CDFW ITP, Major Amendment No. 5 (Permit No. 2081-2001-021-03, Section 2i), the Department conducted sonar-based surveys before each implosion to assess the presence of fish assemblages around the pier. The surveys were intended to identify the presence of any major schools of fish massed in the areas immediately surrounding the pier that could be affected by the blast.

Approximately 4 hours before each scheduled blast, a boat occupied by both construction staff and biologists navigated around the piers using a Hummingbird 1198c GPS Fishing System (fish finder sonar device). Because of the presence of safety and navigational hazards in the area, including explosives, delicate hydroacoustic equipment lines, cables, air hoses, and anchor lines, the boat was required to maintain a safe distance from the piers. For safety reasons, the boat targeted areas approximately 500 feet from each pier. Because of the configuration of the hazards in the area, each survey generally was divided into four quadrants (i.e., northwest, southwest, northeast, and southeast). During the survey within each quadrant, the biologist took photographs of the fish finder display screen and recorded the GPS coordinates and the time. Any potential schools of fish that were detected also were recorded in the same way. Because of the limitations of the survey methodology, determining whether fish seen during this survey were present during the blast or if they were affected by the blast was not possible.

6.5.1.1. Pier E5 and Pier E4 Implosion Results

Fish assemblage data around Pier E5 was recorded at 13 points. All 13 of the sonar readings displayed targets within the water column. Fish assemblage data around Pier E4 was collected at 14 points. Thirteen of the 14 sonar readings displayed targets within the water column. Targets displayed on the fish finder sonar device that may have indicated the presence of a fish assemblage were not confirmed as fish assemblages. Fish finder sonar devices also can display targets for wave action, debris, and other anomalies such as distortion. The fish species salvaged after the implosion of Pier E5 and Pier E4—primarily brown rockfish (*Sebastes auriculatus*) and four species of surfperch— often are found congregated around underwater structures, such as piers, and are not likely to have been swimming in schools within the pelagic zone where they could have been detected by sonar. Therefore, if the targets detected during sonar surveys were fish assemblages, it appears that those fish may not have been injured or killed by the blast, because no pelagic species were recovered post-blast. The results of this survey were sent to CDFW electronically within 72 hours of the blast and are provided in Fish Threshold Criteria.

6.5.1.2. Fish Threshold Criteria

On June 12, 2008, the FHWG—whose members include NMFS's Southwest and Northwest Divisions; the California, Washington, and Oregon Departments of Transportation—together with CDFW and the Federal Highway Administration issued an agreement for establishment of interim threshold criteria to determine the effects of highintensity sound on fish. These criteria were established after extensive review of the most recent analysis of the effects of underwater noise on fish from pile driving in water. The agreed-on threshold criteria for noise to have an injury effect on fish was set at 206 dB peak SPL, 187 dB cSEL for fish over 2 grams (0.07 ounce), and 183 dB cSEL for fish less than 2 grams (0.07 ounce) (FHWG 2008). The FHWG determined that noise at or above these levels can cause damage to auditory tissues and TTS in fish. In addition, a threshold of 150 dB RMS is used by NMFS as the level that elicits a behavioral response, but no injury, in fish. Based on hydroacoustics monitoring results from the Pier E3 Demonstration Project, the linear distances from the implosion to the limit of the FHWG thresholds and the predicted area affected by the pier implosions are shown in Table 6-14. Linear distances used for Pier E3 based on modeling, rather than actual data, also are included for comparison. The decrease in distance to the thresholds based on modeled data compared to measured data indicates the impacts of controlled implosion were much less than originally modeled for Pier E3. The results for the 150dB RMS criteria increased with Piers E4 and E5; however, this is criteria does not indicate injury to fish species. Details on the how the threshold distances were calculated are included in Section 6.3.5.

Table 6-14. Radial Distance to Fisheries Hydroacoustic Working Group Regulatory Thresholds, and Area to be Affected from Piers E4 through E18 Implosions

Threshold	Modeled Distances for Pier E3 (feet)	Distances* for Piers E4 and E5 (feet)	Measured Distances for Piers E4 (feet)	Measured Distances for Pier E5 (feet)
206 dB peak SPL	820	1,165	642	527
187 dB cSEL	2,550	889	720	620
183 dB cSEL	4,000	1,230	1,012	927
150 dB RMS	68,000	4,752	10,487	16,624

Notes:
* = Distances based on measured distances from Pier E3
dB = decibel; cSEL = cumulative sound exposure level; RMS = root-mean-square; SPL = sound pressure level
Sources: Department 2016b; compiled by AECOM in 2016

6.5.1.3. TEMPORARY IMPACTS ON FEDERALLY LISTED FISH SPECIES

The project also was expected to result in temporary impacts on suitable habitat for federally listed fish species, through water quality impacts associated with the blasts. Temporary water quality impacts were anticipated for the following species:

- 393.93 acres for Central California Coast steelhead and green sturgeon;
- 111.52 acres for Central Valley steelhead, winter-run Chinook salmon, and Central Valley spring-run Chinook salmon; and
- 421.20 acres of Essential Fish Habitat.

Based on the results of the November 5, 2015 Pier E3 test blast, impacts on federally listed salmonids or green sturgeon from the test charge were not expected, and impacts on the State-listed longfin smelt were not expected. Similarly, impacts on the other managed fish species from the test charge were not anticipated to be long-term, significant impacts. The results of test blasts conducted on Pier E3 indicated that for a single-test charge within a BAS, the distance to 206 dB peak SPL (the relevant fisheries threshold) was less than 20 feet. For a single test blast, the Pier E3 data shows that the SEL was 180.9 dBe. For two test blasts in a single day, impacts measured at 20 feet from the blast were 183.9 dBe cSEL. All distances were extremely close to the pier and were within or inside the BAS.

6.5.2. Bird Predation Monitoring

6.5.2.1. Monitoring Methods

Bird predation monitoring was conducted immediately after each pier implosion, to assess the level to which fish were affected by the project. Bird predation is defined as birds attempting to prey or feed on other organisms. For the purposes of this project, bird predation can serve as a qualitative indicator of organisms affected by an implosion. Monitoring of predation activity consisted of counting bird strikes on the water surface. (A bird strike on the water surface does not directly correlate with the number of fish injured or killed.) This monitoring was conducted in accordance with Mitigation Measure 2(iii) of the SFOBB Project BO, issued by NMFS on August 8, 2016 for the implosions of Piers E4 through E18.

6.5.2.2. Test Blast Results

A bird monitor was positioned on the bike path during the test blast on October 7, 2016, to monitor for bird species as described in Section 6.4, and then continued to monitor for bird predation activity in the event that bird strikes were observed. No bird predation was observed after the test blasts. Therefore, no bird predation strike counts were done.

6.5.2.3. Pier E5 Implosion Results

On October 15, 2016, bird monitors were in position by 11 a.m. Two monitors were positioned on the new East Span bike path and monitored separate areas before and during the blast. Using hard lines running north-south, away from Pier E5 in both directions, one monitor surveyed areas east of Pier E5 and the other monitor surveyed areas west of Pier E5. A third monitor was positioned beneath the westbound skyway on the footing of Pier E3 of the new East Span near the water level, and surveyed the area under the new bridge structure, facing north. Figure 6-19 shows the locations of each bird predation monitor and the general survey area.

Figure 6-19. Pier E5 Bird Predation Monitoring Locations

Immediately after the Pier E5 implosion (11:57 a.m.), no bird activity was observed. The weather conditions around the former pier degraded rapidly, with high winds and gusts picking up and creating wind waves with "white caps" around the pier within 5 minutes after the implosion. Beginning at approximately 12:04 p.m., a small number of gulls were observed within 500 feet from the pier implosion location, and they appeared to be scouting for prey along the floating lines of debris (wrack) that were in the water. The number of gulls observed in the area ranged from one to five individuals. No other bird species were observed from the bike path. Although a small number of gulls appeared to be attracted to the area between former Piers E5 and E6 because of foam, wrack, and wood debris, very limited bird activity was observed. Striking/diving behavior was not observed; instead, the monitors observed the gulls hovering over the water and landing on the water's surface. The monitors located on the bike path recorded less than five strikes between 11:57 a.m. and 12:21 p.m., none of which were confirmed to result in the collection of a fish. After 12:21 p.m., bird predation monitoring from the bike path was stopped because of the lack of activity observed.

Because the blast was conducted at a high tide, outgoing currents after the blast carried floating items northward beneath the new East Span. A greater amount of bird predation was observed from the location under the new East Span than from the bike path. Activity was observed primarily in the water between Piers E3 and E4 of the new East Span and north of the new East Span. Observations from under the bridge reported bird strikes beginning at 12:14 p.m. From 12:14 p.m. to 12:33 p.m., only one to two strikes per minute were recorded. Beginning at 12:35 p.m., bird activity increased to between seven and 17 strikes per minute, until 12:50 p.m. Predation strike counts beneath the bridge were halted at 12:51 p.m. All bird predation observed from the location under the bridge was done by gulls. No double-crested cormorants (*Phalacrocorax auritus*), brown pelicans (*Pelecanus occidentalis*), terns (*Sterna* spp.), or other sea birds were observed predating on injured or dead fish after the implosion.

6.5.2.4. PIER E4 IMPLOSION RESULTS

On October 29, 2016, bird monitors were in position by 9:30 a.m. Similar to methods used during the Pier E5 implosion, two monitors were positioned on the new East Span bike path and monitored separate areas before and during the blast. Using hard lines running north-south away from Pier E4 in both directions, one monitor surveyed areas east of Pier E4 and the other monitor surveyed areas west of Pier E4. A third monitor was positioned beneath the westbound skyway on the footing of Pier E3 of the new East Span near the water level and surveyed the area under the new bridge structure, facing north.

Figure 6-20 shows the locations of each bird predation monitor and the general survey area.

Immediately after the Pier E4 implosion (11:23 a.m.), bird predation monitoring was begun by the two monitors on the bike path, and the third monitor on the Pier E2 footing of the new East Span. After the blast, the currents generally drifted southwest. With the exception of a single strike (12:02 p.m.) recorded under the new East Span, all bird strikes were recorded west and southwest of the site of the former Pier E4. Strikes were first observed at 11:27 a.m., with strike activity peaking between 11:29 a.m. and 11:38 a.m., during which time bird strikes ranged from approximately six to 15 strikes per minute. Bird strikes were recorded until approximately 11:46 a.m., when activity tapered off. In addition to bird strikes, bird activity also was high, with up 20 birds at a time observed either circling the area or floating on the water. All recorded bird strikes were made by gulls. One brown pelican was observed floating in the water near the pier but was not observed foraging. No double-crested cormorants, terns, or other sea birds were observed predating on injured or dead fish after the implosion.

6.5.3. Fish Salvage

6.5.3.1. Monitoring Methods

To further understand the quantity, species, and nature of injury or mortality to fish, biologists in the boats collected dead or moribund fish from the water for further examination, immediately after the implosions of Piers E4 and E5. The biologists navigated around the pier (when it was deemed safe to do so after the implosion) and collected any fish observed floating on the water surface, using a long-handled net. Fish also were collected from the debris management boats that were operated by the contractor, and they were stored in a bucket for further identification and assessment on shore by a biologist.

6.5.3.2. Pier E5 Implosion Results

Fish salvage after the Pier E5 implosion was conducted by two dedicated boats, each with two biologists positioned north of Pier E5, as well as by the construction contractor within the containment boom encircling Pier E5.

After the implosion, the construction contractor began work to cleanup and contain debris from the area within the containment boom. Specially marked buckets were placed on each contractor skiff, so that fish collected could be held separately from other debris. The collection of fish within the containment booms began at approximately 12:05 p.m. and continued for approximately 30 minutes.

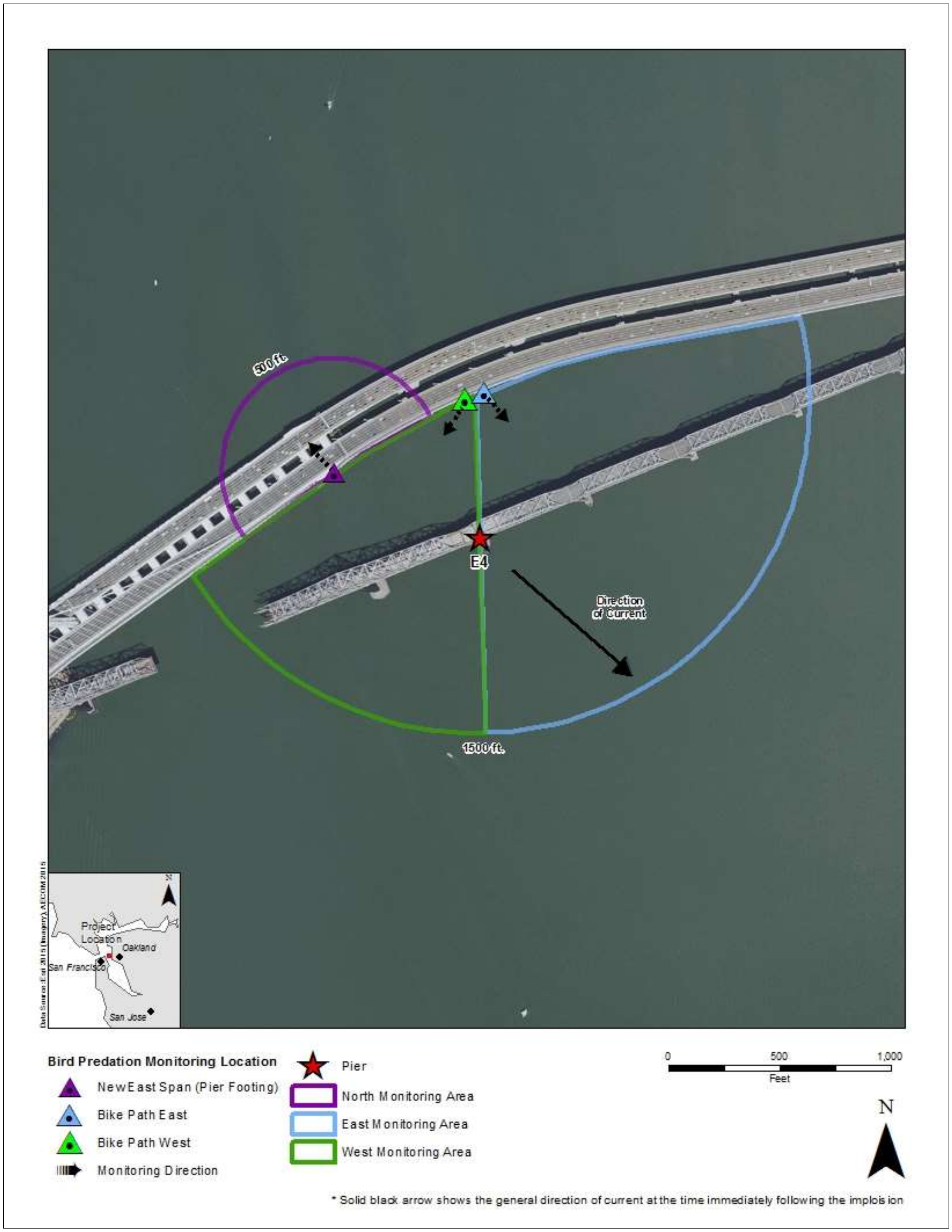


Figure 6-20. Pier E4 Bird Predation Monitoring Locations

The fish collection boats proceeded to collect fish between approximately 700 and 1,500 feet northwest and northeast of the former Pier E5. As the tide began to turn, fish floating in the water column drifted northward into the area where the dedicated collection boats were located. Fish collection was performed until approximately 1 p.m., using long-handled nets. After collection was completed, one boat proceeded to rendezvous with the contractor's barge to collect the fish found within the containment boom.

Collected fish were organized by size and species, and then were counted. In total, 193 individual fish were collected—120 fish from inside the containment boom and 73 from outside the containment boom. Five species were collected, with brown rockfish (*Sebastes auriculatus*) being the most commonly collected species (95 percent). Other species collected included rainbow surfperch (*Hypsurus caryi*), shiner surfperch (*Cymatogaster aggregata*), walleye surfperch (*Hyperprosopon argenteum*), and rubberlip surfperch (*Rhacochilus toxotes*). Table 6-15 summarizes the fish collected. No Endangered Species Act or California Endangered Species Act listed species were collected or observed. No species managed under a Fishery Management Plan were collected or observed.

Table 6-15. Pier E5 Fish Salvage Results

Species	Size Category (fork length in millimeters [mm])	Number Outside Containment Boom (collected by biologists)	Number Inside Containment Boom (collected by contractor)
Brown rockfish	Less than 70 mm	9	6
	71–110 mm	61	74
	111–185 mm	1	29
	215 mm	0	1
	235 mm	0	1
	270 mm	0	1
Rainbow surfperch	115–150 mm	1	2
Shiner surfperch	93–96 mm	0	3
	110–118 mm	1	1
Walleye surfperch	125 mm	0	1
Rubberlip surfperch	400 mm	0	1
Total		**73**	**120**
Source: Compiled by AECOM in 2016			

6.5.3.3. Pier E4 Implosion Results

Fish salvage after the Pier E4 implosion was conducted both inside and outside a containment boom that encircled Pier E4 at approximately 100 feet. Fish collection was conducted outside the boom by four biologists on two dedicated boats, positioned north of Pier E4 and inside the boom by the contractor in multiple small skiffs.

After the blast, the construction contractor began work to cleanup and contain debris from the area within the containment boom. Specially marked buckets were placed on each contractor skiff, so that fish collected could be held separately from other debris. The collection of fish within the containment booms began at approximately 11:27 a.m. and continued for approximately 40 minutes.

Currents generally moved towards the southwest direction after the blast, and biologists in boats proceeded to collect fish approximately 5 to 10 minutes after the blast. Deceased or moribund fish were collected within areas that were approximately 500 to 1,500 feet northwest, west, and southwest of the former Pier E4. In general, most fish were collected west and southwest of Pier E4. Fish collection was conducted until approximately 12:30 p.m., using long-handled nets. After collection was completed, one biologist’s boat rendezvoused with the contractor’s barge and collected the fish found within the containment boom.

Collected fish were organized by size and species, and then were counted. In total, 210 individual fish were collected—28 fish from inside the containment boom and 182 from outside the containment boom. Four confirmed species were collected, as well as four unidentified surfperch. Brown rockfish was the most commonly collected species (96 percent). Other species were collected, including rainbow surfperch (*Hypsurus caryi*), shiner surfperch, and walleye surfperch. Table 6-16 summarizes the fish collected. No Endangered Species Act or California Endangered Species Act listed species were collected or observed. No species managed under a Fishery Management Plan were collected or observed.

6.5.4. Pacific Herring Monitoring

Per previous herring work waiver authorizations, CDFW has required the Department to monitor for evidence of recent herring spawns within 1,640 feet of any activity that may affect schools of herring or spawning herring during the herring spawning season.

Table 6-16. Pier E4 Fish Salvage Results

Species	Size Category (fork length in millimeters [mm])	Number of Fish Collected Outside the Containment Boom	Number of Fish Collected Inside the Containment Boom
Brown rockfish	Less than 70 mm	20	2
	71-110 mm	112	11
	111-150 mm	35	8
	171-205 mm	-	5
	151-210 mm	7	-
	264 mm	1	-
Rainbow surfperch	170 mm	1	-
	225 mm	1	-
Shiner surfperch	106 mm	1	
	115 mm	-	1
Surfperch spp.	115 mm	1	-
	118 mm	1	-
	126 mm	1	-
	170 mm	1	-
Walleye surfperch	145 mm	-	1
Total		**182**	**28**
Source: Compiled by AECOM in 2016			

The Department received authorization from CDFW and was issued a Pacific Herring Work Waiver to continue in-water work into December 2016, if necessary, but it was not invoked because all cleanup activities were completed by November 30, 2016. No work associated with the project occurred during the herring spawning season; therefore, no herring surveys were required or performed.

Chapter 7. Effectiveness of Project Means and Methods

This chapter reports evidence that the construction techniques (i.e., means and methods) used to remove Piers E3, E4 and E5 from the waters of the Bay were effective. The construction techniques used to minimize environmental impact also were repeatedly successful, demonstrating that the extra work to protect the environment was not detrimental to the ultimate success of the physical removal of the piers within the waters of the Bay from a construction, environmental, schedule, and cost perspective.

7.1. Construction Effectiveness

As discussed in Chapter 2, Piers E3, E4, and E5 each had its own pier-specific blast design that incorporated a post-blast cleanup to remove relatively small amounts of rubble material to a specified elevation, to return the Bay to its original conditions and meet permit requirements. All three blast events collapsed the overwhelming majority of the caisson material into the deep caisson voids below the bay floor. As planned, and following each pier blast event, sonar submarine surveys were conducted to map elevations of the Bay floor. These surveys showed the structures were successfully collapsed and offered information to guide the relatively modest cleanup and removal that was needed. The submarine surveys were conducted using a small vessel with side-scan sonar equipment.

Figures 7-1 and 7-2 show one of the typical vessels used and the side-scan sonar, respectively. During the sonar scans, some information on elevations of the Bay floor started to become available almost immediately, providing interactive information to guide the continuing operation of the sonar survey. After the necessary data were collected, processed, and reviewed, cleanup operations could begin. In all cases (i.e., Piers E3, E4, and E5) the sonar scans quickly made available indisputable evidence that the blast designs and execution of the blast events were effective in collapsing the upper portions of the caissons as planned. In addition, the sonar scans successfully provided critical information to guide the subsequent cleanup efforts.

Figure 7-1. Typical Vessels for Conducting Side-Scan Sonar Survey

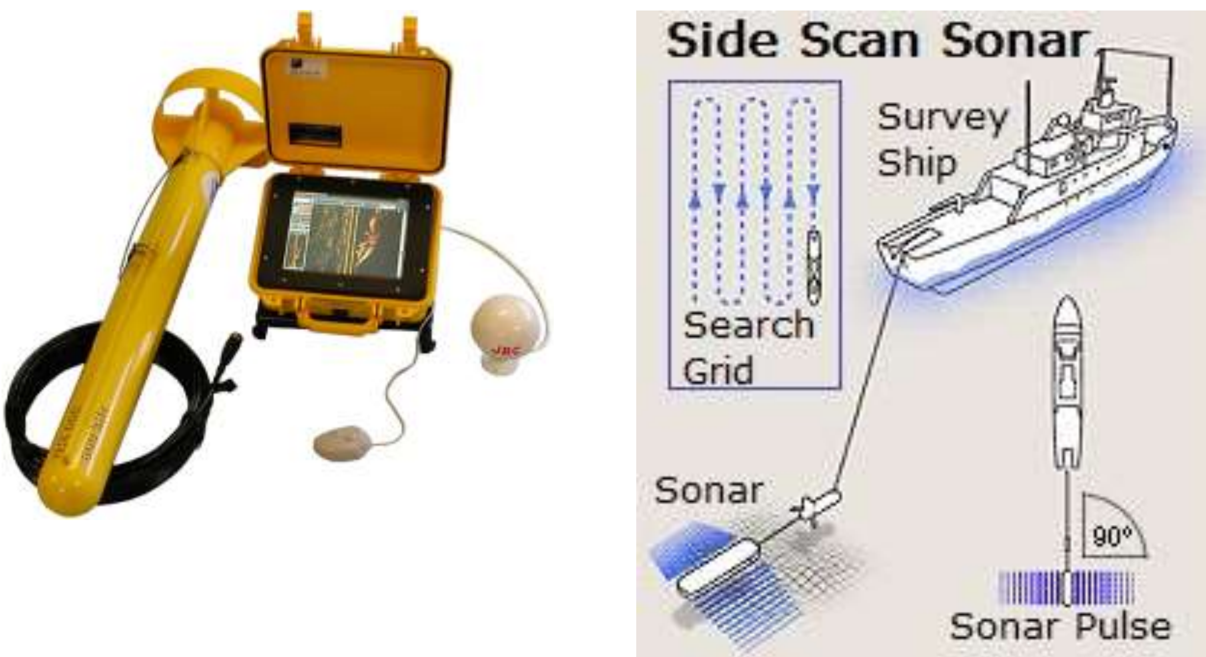


Figure 7-2. Side-Scan Sonar Equipment

Figures 7-3, 7-4, and 7-5 show the Bay floor at and around Piers E3, E4 and E5, respectively. In each image, color is used to show the varying elevations surrounding the piers. A color elevation scale is shown in each image, to guide interpretation. In the case of each figure/pier, it is valuable to recognize several important points. First, each pier foundation is in a scour hole that is measurably deeper than the natural surrounding Bay floor. The natural Bay floor elevation is the Bay floor elevation that would exist if the bridge piers never would have been constructed. The natural Bay floor exists outside of the local region around the piers where scour has occurred, creating a scour hole. A scour hole is created by water moving around and adjacent to an obstructing pier at a relatively higher velocity than water moving through the same channel of flow not affected by the obstructing pier. The water at the higher velocity adjacent to the pier will carry more Bay floor sediment, which leads to a cutting, or scour, around a pier effectively digging out a scour hole around each pier. The color scales associated with each figure offer a numerical measure of the scour depth around each pier. After the obstructions of the piers are removed from the waterway, the scour holes will fill with sediment in a similar way to how the Bay shipping channels fill regularly with sediment carried by watershed and tidal flows. Second, the images offer an understanding of the past and future natural Bay floor elevations outside the scour holes.

By interpolation of Bay floor elevations outside the scour holes and across the holes, a confident prediction of a future natural and stable bay floor elevation could be established at the locations of each pier across the scour holes. With the future bay floor elevation well established, an elevation to which the piers should be removed could be determined by subtracting a conservative number from the predicted natural Bay floor elevation. The project team proposed removing the foundation material to 3 feet below the predicted natural Bay floor, to provide a conservative approach to confidently developing a natural material on the Bay floor that would support organisms that can live on and in the Bay floor silts. Third, the images offered a well-defined measure to monitor recovery of the Bay floor. Future sonar scans can be compared to the original post-cleanup sonar scans, to track and judge the Bay floor recovery.

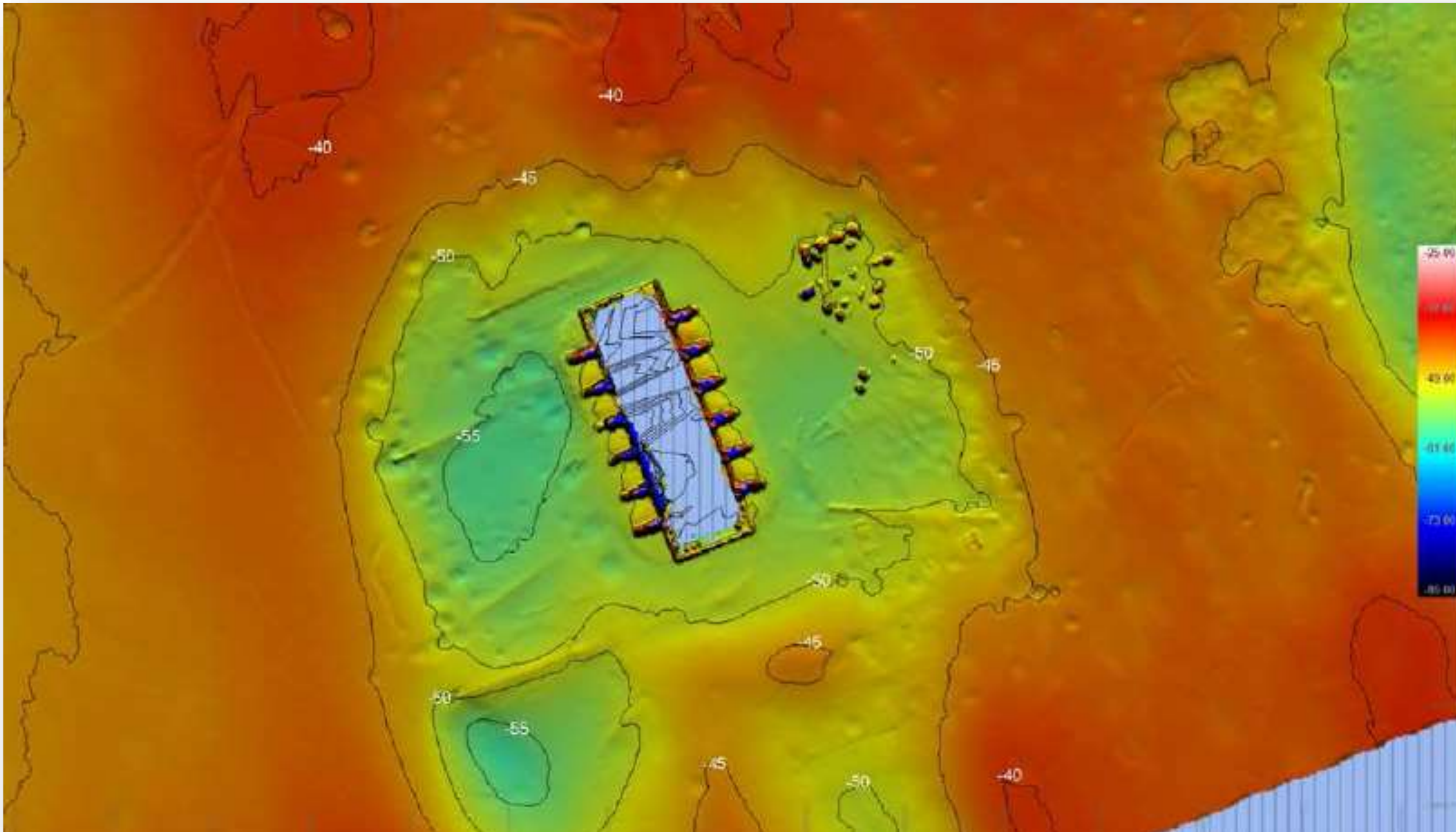


Figure 7-3. Bay Floor at Pier E3, Pre-Blast

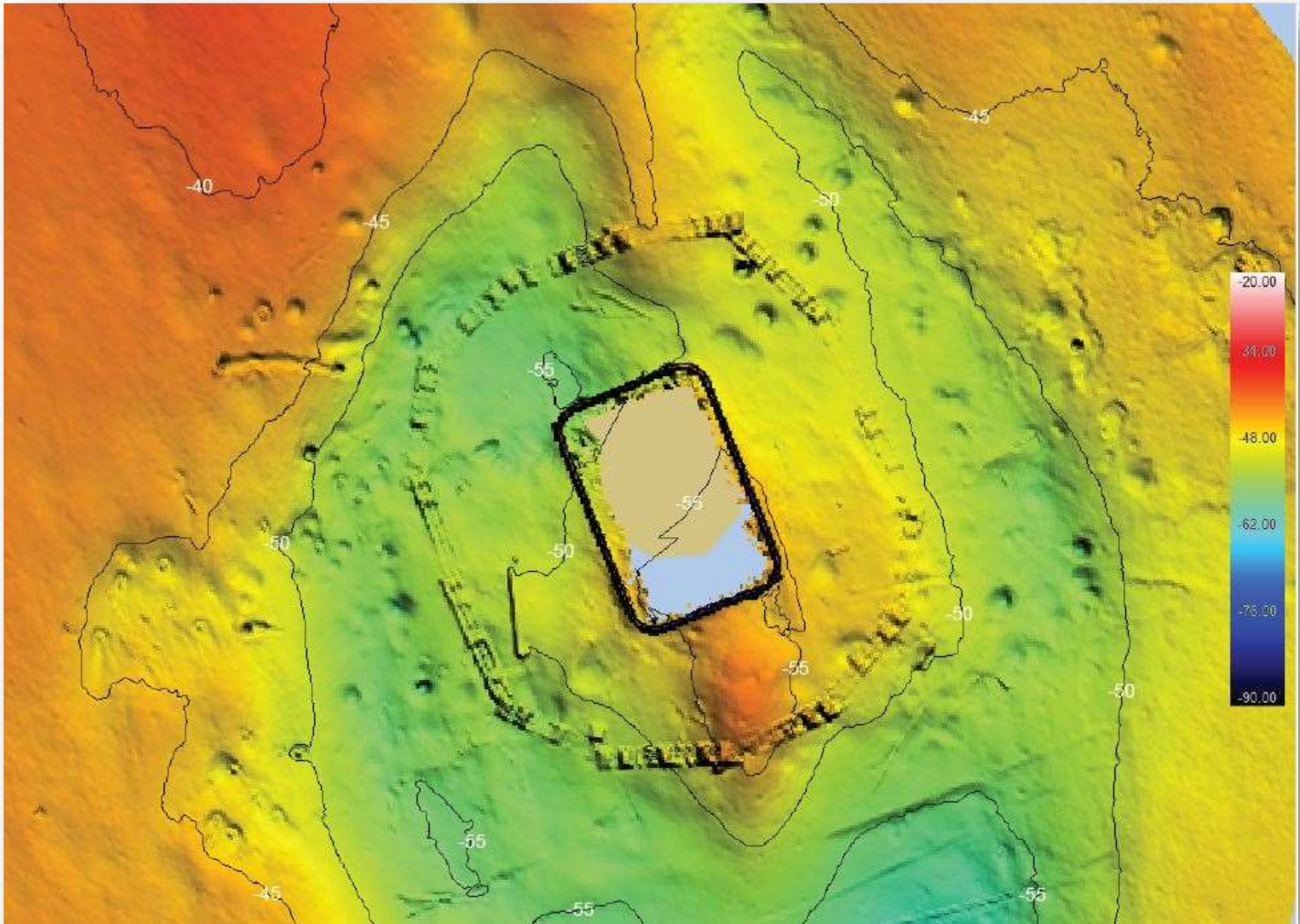


Figure 7-4. Bay Floor at Pier E4, Pre-Blast

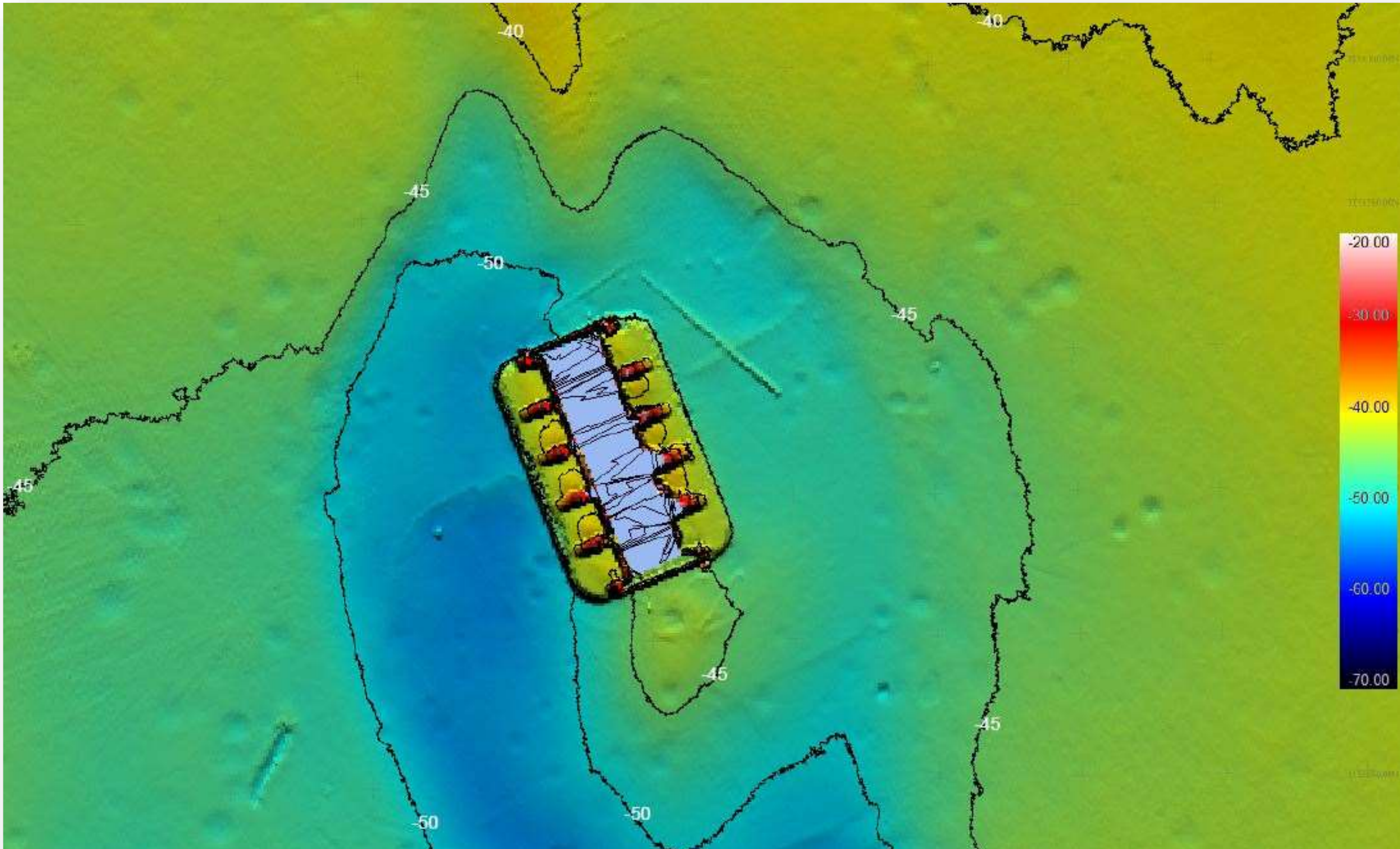


Figure 7-5. Bay Floor at Pier E5, Pre-Blast

Figures 7-6, 7-7, and 7-8 show post-blast and cleanup at Piers E3, E4 (to-date), and E5, respectively. For Piers E3 and E5, and comparing the pre-and post-blast cleanup images, it can be determined that the post-cleanup elevations of the blast rubble are at the specified removal limits. These images will be compared to images developed from future sonar scans, to document Bay floor recovery. The post-blast sonar scan of the Pier E4 region shows some additional cleanup is necessary. The cleanup was not completed this year to avoid in-water cleanup during December, when protected herring may be present. The cleanup near Pier E4 will be completed similarly to the cleanup at Piers E3 and E5 following the restricted time windows. The sonar scans show removal work at Piers E3, E4, and E5 has been very successful.

Figure 7-9 shows a follow-up image at Pier E3. The image in Figure 7-9 was developed with data collected in a sonar survey 6 months after the survey that provided the data for the image shown in Figure 7-6. Comparing the two images offers clear evidence that even after only 6 months, the Pier E3 scour hole and caisson hole in fact are filling in naturally, as expected by project engineers.

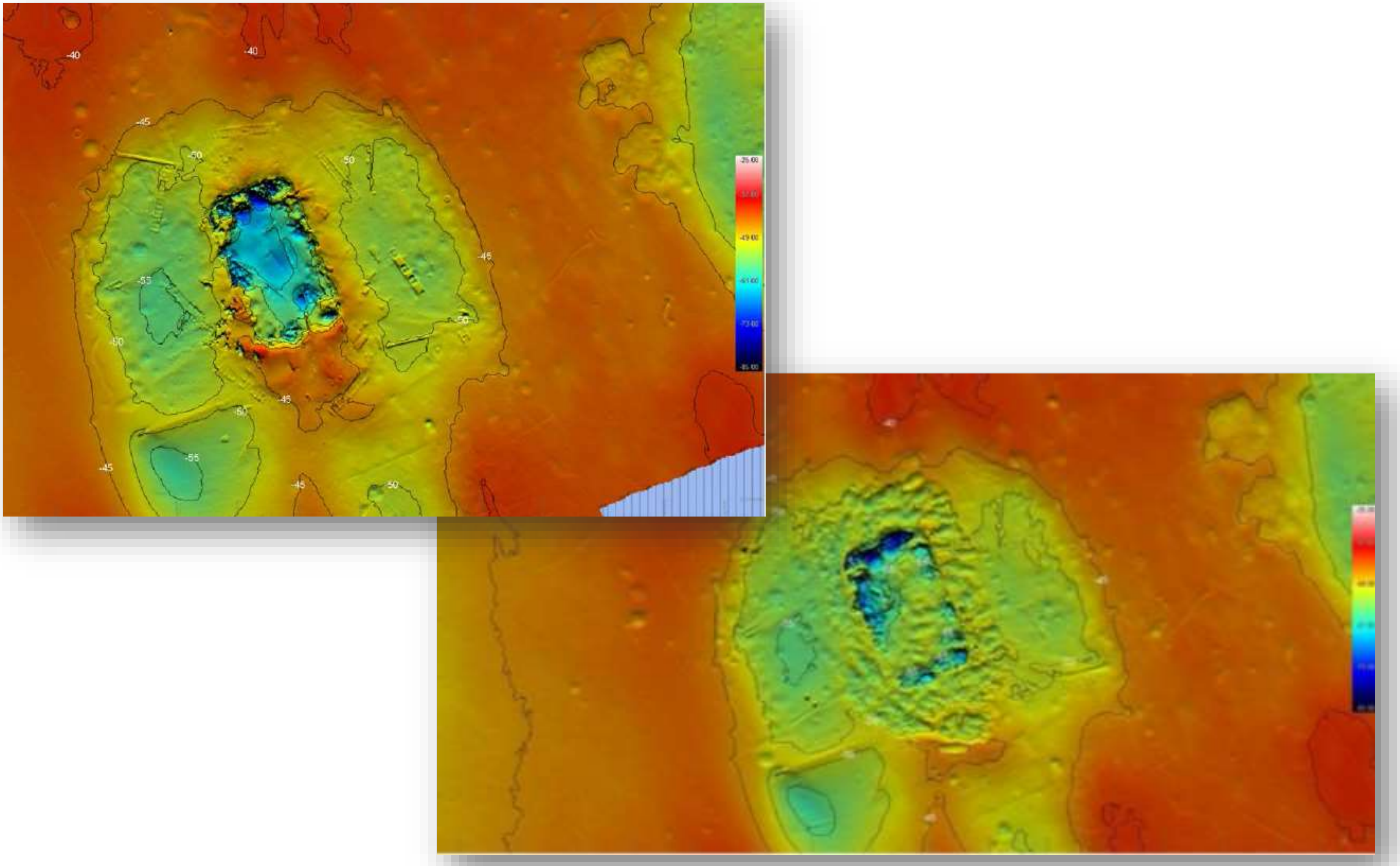


Figure 7-6. Post-Blast and Cleanup at Pier E3

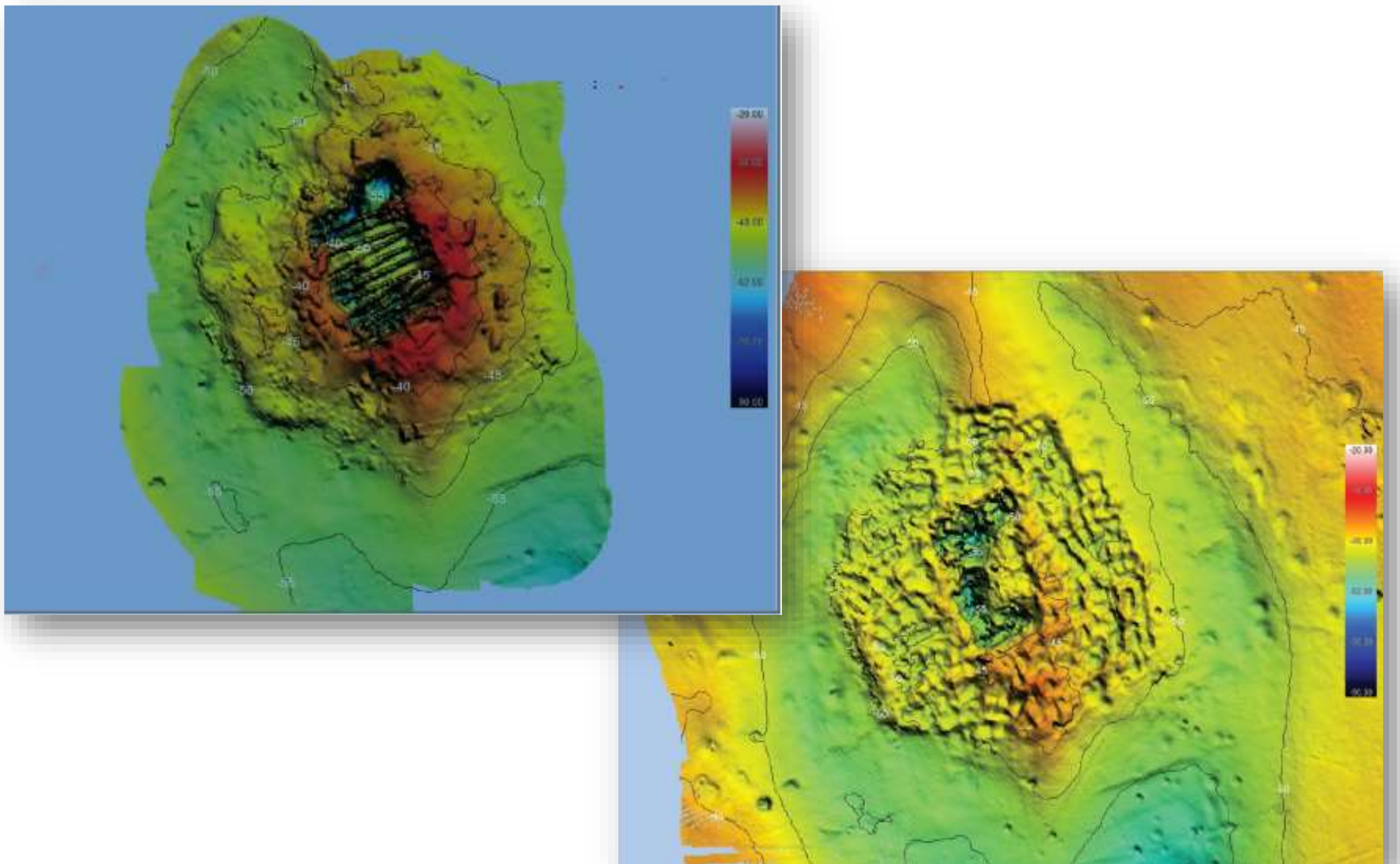


Figure 7-7. Post-Blast and Cleanup at Pier E4

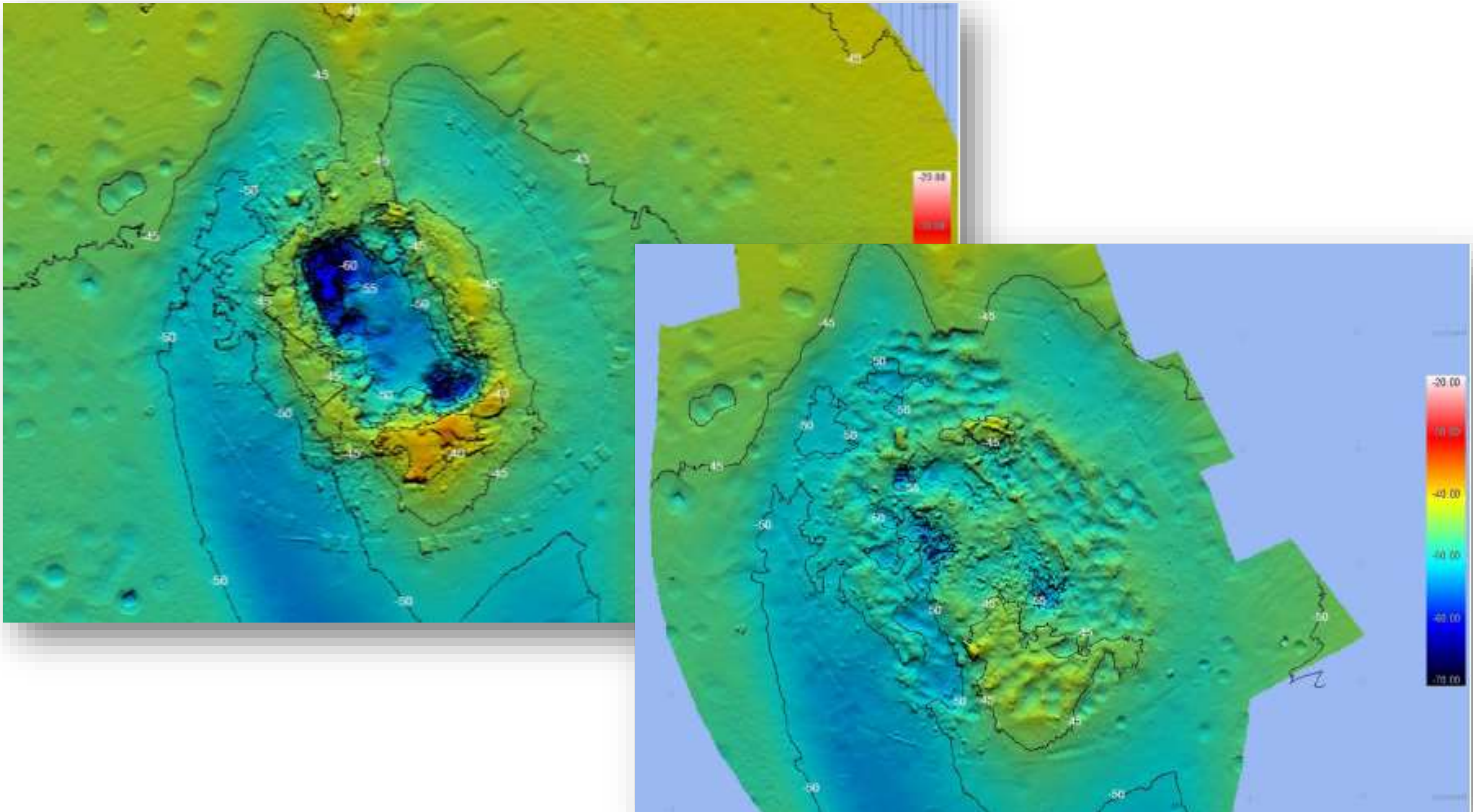


Figure 7-8. Post-Blast and Cleanup at Pier E5

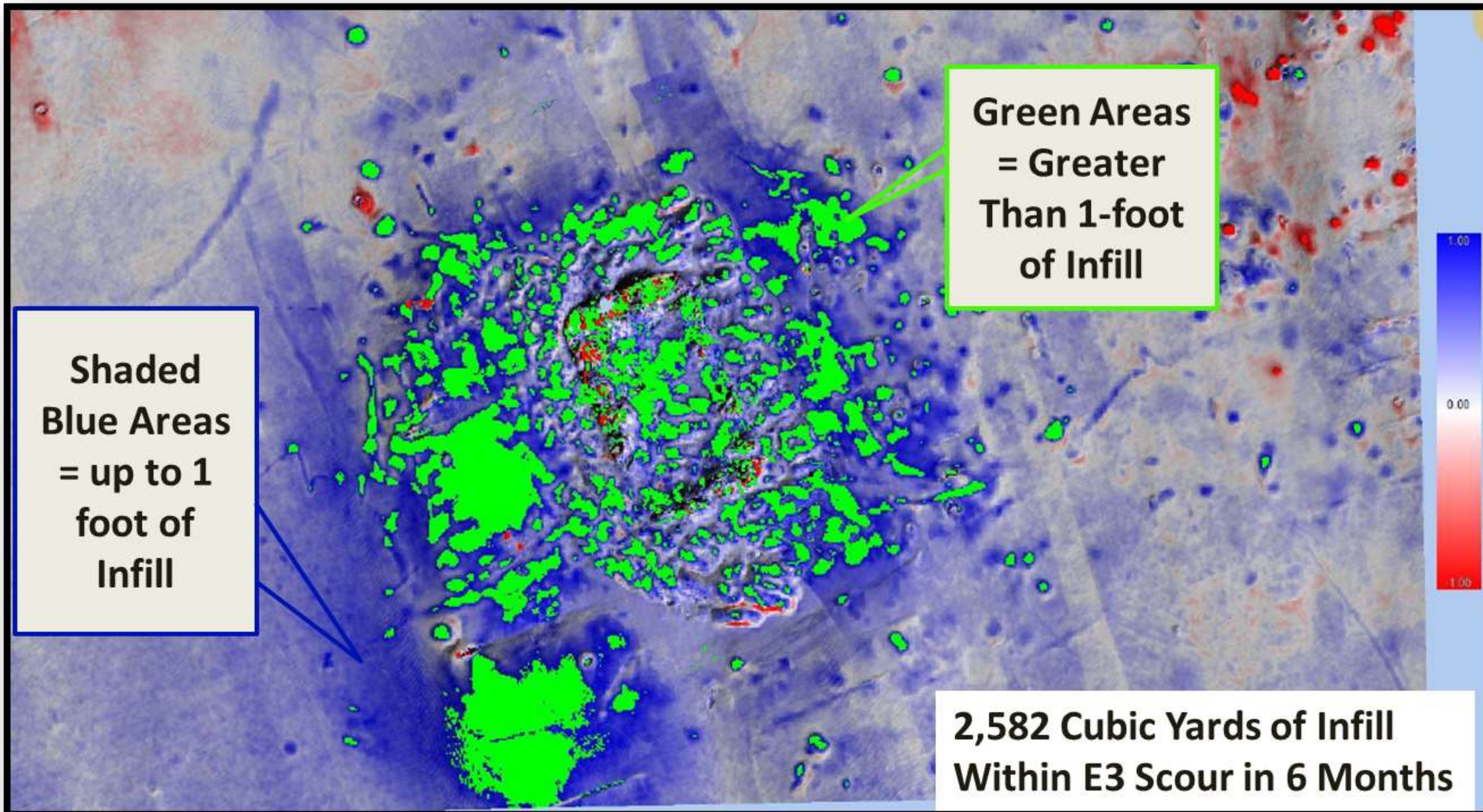


Figure 7-9. Bay Floor 6 Months after Pier E3 Blast

7.2. Environmental Effectiveness

Work performed by all personnel was very effective with respect to environmental parameters. The environmental personnel did an outstanding job of communicating the critical items of environmental concern to the design and construction personnel. With that information, the entire project team developed strategies and plans necessary to protect the environment, as well as develop and implement data acquisition systems to document actual field measurements during and following the blast events, to offer facts to guide future work in the areas of water quality, fisheries, marine mammals, and nearby eelgrass habitat. The data collected and the knowledge gained from that data is groundbreaking and is redefining many previously held, best-guess estimates that, while based on the best available information at the time, were substandard when compared to actual verified blast event data.

All parties involved, including environmental resource agencies, agreed that the Demonstration Project was appropriate, and the old East Span Pier E3 was selected as the best test site. Because of a lack of similar project data, conservative requirements and mitigations were applied. Following the Pier E3 blast event, those conservative requirements and mitigations were evaluated in comparison with the actual data collected. The actual experiences showed much smaller impacts than assumed in all areas, including water quality, fisheries, and marine mammals. Good examples are shown in Figures 7-10 through 7-13. Figure 7-10 shows the conservatively modeled distances to fish criteria thresholds before the actual field data collected from the Pier E3 blast event were available, while Figure 7-11 shows the actual distances to the field-measured thresholds. Figure 7-12 through 7-15 show the differences between conservatively modeled distances to pinniped and high-frequency porpoise criteria thresholds before the actual field data collected from the Pier E3 blast event were available, compared to the actual distances to the field-measured thresholds. By simple comparison of the radii of the threshold circles, the measurements made by the contractors, engineers, and scientists obviously were effective. The actual data, collected appropriately, clearly has offered accurate and beneficial information. Reliance on actual data has led to much better environmental analyses, clearer understanding, and development of more appropriate requirements.

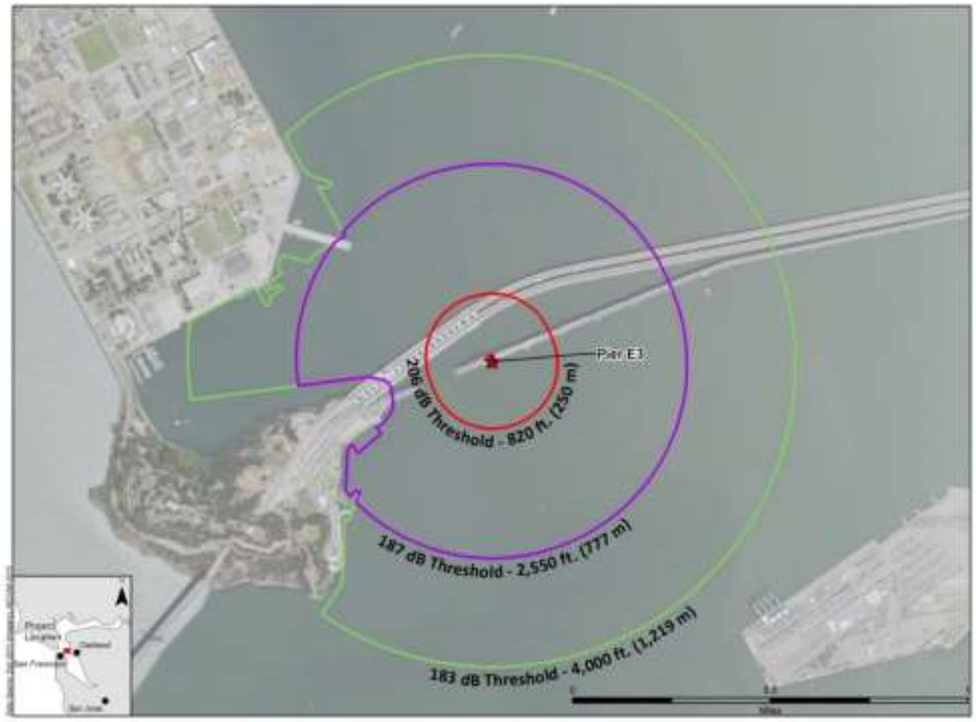


Figure 7-10. Modeled Isopleths to Fish Threshold Criteria, Pier E3

Figure 7-11. Measured Isopleths to Fish Threshold Criteria, Pier E3

Figure 7-12. Modeled Isopleths to Pinniped Threshold Criteria, Pier E3

Figure 7-13. Measured Isopleths to Pinniped Threshold Criteria, Pier E3

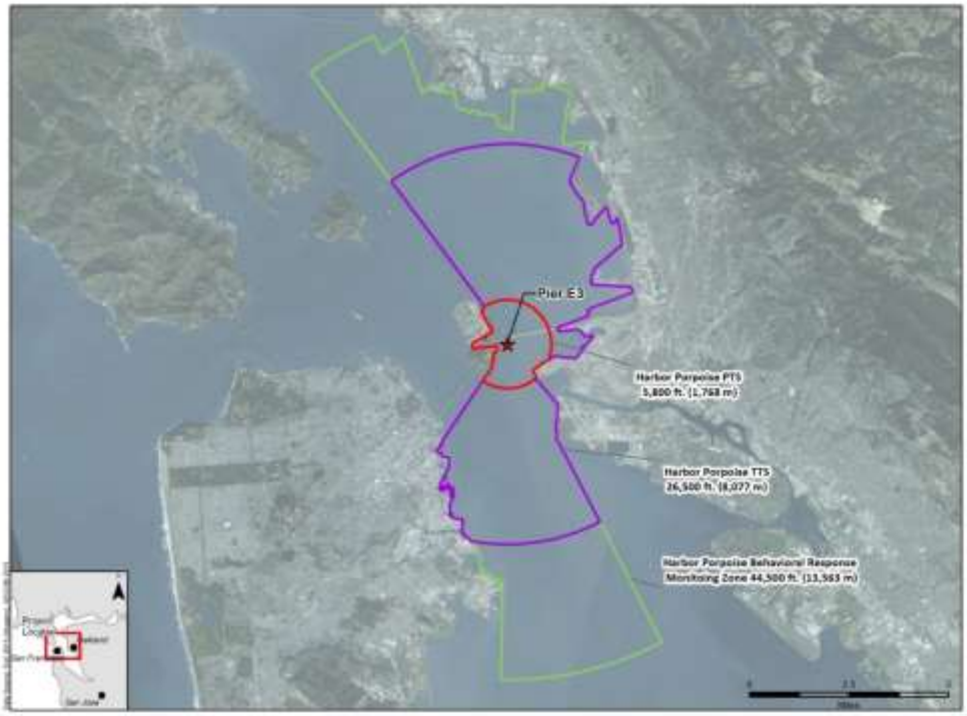


Figure 7-14. Modeled Isopleths to HF Porpoise Threshold Criteria, Pier E3

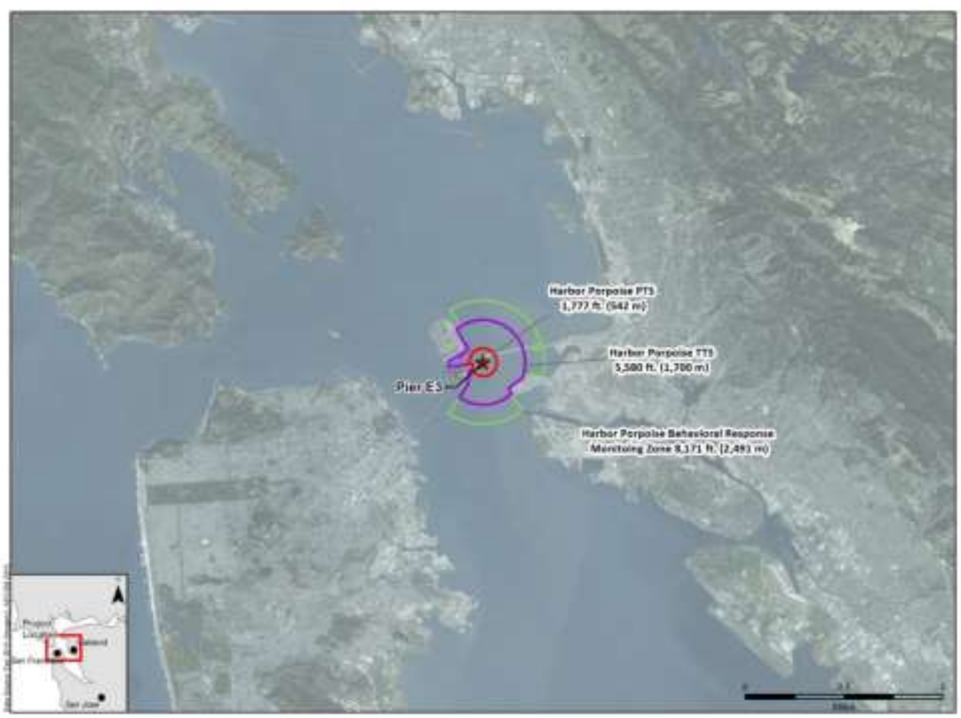


Figure 7-15. Measured Isopleths to HF Porpoise Threshold Criteria, Pier E3

Table 7-1 summarizes the predicted water quality effects prior to the Pier E3 Demonstration implosion versus the actual water quality effects observed in the field for each of the three implosions. Comparing the conservatively modeled results to the actual measured results show that all water quality impacts were minimal, better than conservatively modeled before having the benefit of actual field-measured data, and met water quality objectives (WQO). The work, measurements, and analyses of the multiple water quality parameters clearly were effective in documenting the minimal impacts on the Bay waters from the Pier E3 blast event. In addition, specifically placed sensors near the eelgrass beds along TI and Alameda Island were effective in documenting that no changes occurred in water quality in the eelgrass habitat.

The BAS as designed, constructed, and operated was a first of its kind in size. Chapter 3 discusses the high levels of BAS effectiveness in reducing the pressure/sound peaks. Figure 3-4 shows, in log scale, the reduction. The efficiency of the BAS can be calculated several ways that can generate numbers from 70 percent to more than 90 percent; it is reasonable to use a round number of 75 percent efficiency. Regardless of the exact number used to report the efficiency, the BAS was clearly a success and very effective.

Over all, the effectiveness of the environmental-related work associated with Piers E3, E4, and E5 greatly minimized impacts on the environment and generated groundbreaking data. This information can be used to improve the quality of the remaining work to remove SFOBB marine piers from the Bay waters and can be used to improve countless other projects. The impressive repeatability of the work during all three blast events at Piers E3, E4, and E5 is leading to a high level of confidence in the dataset itself and confidence in applying it to work at other piers. This is particularly impressive because much of this work was based solely on research, conducted during design and construction phases of a massive project. Combining such vastly different work into a single project typically leads to substantial delays and cost increases. Such disappointments were avoided on this project, by the close coordination and cooperation by all members of the project team.

Table 7-1: Comparison of Predicted and Observed Water Quality Effects from Implosion of Piers E3, E4, and E5

Pier	Maximum pH/ Increase in pH	Water Quality Objectives/Background Conditions (pH)	Water Quality Parameter for which No Effects Observed	Limited Effects Observed
Pier E3 (Predicted)	9.0 – 10.0	• Below WQO (8.5) within 1 hour and background within 6 hours	Slight increase turbidity, no change in dissolved oxygen or temperature	Slight increase of dissolved chromium, above background but below WQO
Pier E3	9.0 (Estimated) 8.7 (Measured) pH increased by up to 1 standard pH unit	• Below water quality objective (WQO) in approximately 1 hour • Return to background conditions in approximately 4 hours	No increase of turbidity, dissolved oxygen, temperature	Dissolved chromium was transiently elevated above background but remained below WQO
Pier E4	8.44 (Measured) pH increased by approximately 0.6 standard pH unit	• Remained in WQO range (6.5 to 8.5) during entire measurement period • Return to background conditions in less than 1 hour	No increase of dissolved oxygen, temperature	Turbidity remained within WQO, increasing to just less than 50 NTU, and then returning to background in less than one hour
Pier E5	7.93 (Measured) pH increased by approximately 0.1 standard pH unit	• Remained within WQO range during entire measurement period • Return to background conditions in less than 1 hour	No increase of turbidity, dissolved oxygen, temperature	No parameters

7.3. Schedule Effectiveness

The Contractor Bid schedule for removal of the main piers that have been removed or are currently contracted for removal, Piers E3 through E18, were presented in line 9 of Figure 1.3. Line 10 shows the trending early completion dates for these piers.

Lines 1, 4, and 8 represent the old SFOBB East Span demolition timeline without taking advantage of upcoming opportunities or impacts. Lines 2, 6, and 10 represent the old East Span demolition timeline taking advantage of upcoming opportunities or impacts. A comparison of lines 2, 6, and 10 with lines 1, 4, and 8 clearly shows the opportunity for early completion of work for Piers E3 through E18. This is mainly because of the project team's opportunistic approach to constant interaction and willingness to take advantage of opportunities and quick response to challenges, the success of the California Engineering Contractors–Silverado Joint Venture (CEC-Silverado) contractor and the project team finishing early on the Cantilever removal (line 3), the removal of the 504- and 288-foot trusses to dates (line 6), the success of K-M, and the support of the TBPOC Project Management Team on the removal work (line 10). In fact, if final work on 504- and 288-foot truss removal continues as CEC-Silverado currently plans, they will finish in spring 2017 (line 6), creating the opportunity for an early finish in removing the remaining Piers E6 through E18, an entire year early, if permitting agencies support the work required to be completed (lines 10 and 11).

The project team currently is working with CEC-Silverado, K-M, and the environmental agencies to establish conditions to allow for the early finish as shown in line 10. The effectiveness, measured by schedule, of the progressing removal work on the old SFOBB East Span has been outstanding, with an approximate 1 year early start on the cantilever and an additional 1 year early finish of the same cantilever; a resulting 1 year early start and a potential additional 1 year early completion on the 504- and 288-foot trusses removal; and now a potential early finish of removal of Piers E3 through E18. It should also be recognized that the diligent planning and sequencing of the three removal contracts produced outstanding results with the schedule effectiveness.

7.4. Cost Effectiveness

The use of controlled blasting techniques to remove the marine foundations, coupled with the CMGC contracting methods discussed in Chapter 2, have resulted in significant cost savings. Programmed costs and their associated risks have been decreased by more than $60 million in Capital Outlay (CO) costs when compared to alternative removal methods, mainly mechanical removal in a marine cofferdam. The reduction of the overall number of years required to complete the removal of the existing SFOBB will also result in significant savings of over $30 million in Capital Outlay Support (COS) costs.

The Pier E3 Demonstration project successfully removed the first SFOBB foundation from the SF Bay and was also a financial success for the program. The final project cost of $16.5 million was well under the budget approval of $18.5 million and returned of 90% of the project contingency to the program for use on future projects. After the 2016 construction season, the Pier E4 to Pier E18 Contract is looking equally promising in terms of both project costs, COS budgets, and schedule.

It should also be noted that these cost savings have been achieved with a significant CO cost investment in environmental stewardship through operation of the BAS and the myriad environmental monitoring activities. On the Pier E3 Demonstration Project over 30% of the project expenditures can be attributed to these activities Similar investments in COS to plan, design, inspect, and administer these activities were necessary to successfully achieve the results that were planned and designed by the PDT and K-M.

Chapter 8. Summary and Conclusions

The following is a summary of the information provided in this report in a brief, efficient and clear manner and format. The conclusions offer a final set of statements that are supported by actual data and experience collected during removal of Piers E3, E4, and E5. Furthermore, the conclusions offer a clear path of opportunity forward to removing the remaining piers through Pier 18 with similar or improved success.

8.1. Summary

The blast design was presented in Chapter 2. The blasts were designed by licensed experts and precisely timed by a computer controlled system. The construction and implementation of these blast system components also were closely inspected. The blast events were constructed from not a single large event, but from many much smaller events that generated a fraction of the potential pressure/sound wave amplitudes through the water. In all cases, the Pier E3, E4, and E5 blast events were executed as designed.

The Blast Attenuation System was presented in Chapter 3. The BAS design was fundamentally based on principles common in physics and engineering; the previous success of USACE work at Lock and Dam 26; and the previous design and experience of the Marine Pile Driving Energy Attenuation System, developed in preparation for the SFOBB Skyway project, used to aid the Benicia Toll Bridge project. Field data recorded during the blast events at Piers E3, E4, and E5 show the BAS was very effective in substantially reducing the amplitudes of the overpressure/sound waves.

Chapter 4 presents the responses of nearby structures to pier blasting events. In all cases, the recorded responses of the nearby structures during and following the blast events were minor and of no recognizable concern to the structures or their required performances. The recorded motions on the BART Transbay Tube at the closest location document a peak displacement of 0.008 inches. In the case of the BART Transbay Tube, it is valuable to note the distances between Bay Bridge piers to be imploded and the Transbay Tube only increase as the projects moves forward. Peak recorded motions on EBMUD's sewer outfall pipe were 0.6 inches. No damage to either structure was observed or is believed to have occurred.

Chapter 5 discusses impacts on water quality and air quality. The large, well-designed water quality monitoring team—with a complex array of scientific instrumentation deployed prior to, during, and following the blast events—generated an abundance of actual in-water field data, documenting that the waters of the Bay were affected very minimally during and following the blast events. The field data showed that changes in the Bay either did not measurably deviate from baseline conditions or were changed to such a small degree that conditions returned to baseline levels within a few hours.

Changes to air quality conditions were recognized to be of little or no concern, because the anticipated changes were of such short and mild dimensions. It is of value to note that the Department's Blaster-in-Charge was responsible for evaluating and then sounding an "all clear" signal following each blast event, based on a number of conditions, including an evaluation of air quality.

Chapter 6 discusses the impacts on wildlife from the blast events. Marine invertebrate species attached to the concrete piers and fish very nearby the piers within the BAS perimeter were killed by the unattenuated blast. However, the blast design and the BAS proved to be very effective in protecting wildlife, as clearly shown by no scientific signs of harm to the "Caged Fish Study" salmon from the blasts. The overwhelming majority of juvenile Chinook salmon (a listed species) that were studied as close as 120 feet from the blasts were not killed and showed no signs of damage to internal organs related to the effects of the attenuated blasts. The results are undeniable, impressive, and generally great news for natural resource managers, engineers, scientists, contractors, and taxpayers.

Overpressure/sound wave data collected also shows that the pressure/sound waves were tremendously reduced by the BAS. The corrections to the conservative estimates of distances to various fish/marine mammal threshold levels from the Pier E3 blast, down to the levels employed and verified during the Pier E4 and E5 blast events, demonstrate well the value of the investment made by the TBPOC to measure and more accurately define actual impacts from the overpressure/sound waves.

Chapter 7 presents evidence of the project's effectiveness. In all three blast events, the construction work has been effective, and the environmental impacts have been reduced to a level below what was expected/predicted, thus demonstrating a new level of environmental effectiveness. This success offers an opportunity to complete upcoming work similarly with an effective schedule and cost. It is important to recognize the project team—contractors, engineers, scientists, biologists, and others—have worked well together, though at times quite intensely, to quickly advance the state-of-knowledge, state-of-the-art, and state-of-the-practice to improve the Bay's environment, offering even further opportunities to improve that environment. Without an extraordinary level of effort by many individuals, the effectiveness that has been realized would not have been achieved. To continue the success of the project seen at Piers E3, E4, and E5, the level of effort, solid science and engineering, and practical construction must continue.

8.2. Conclusions

The experiences associated with the Pier E3 Demonstration Project in 2015 and similar experiences associated with the removal of Piers E4 and E5 in 2016 can be expressed in the following straight-forward statements:

a) The use of multiple smaller charges, spaced apart in time for environmental reasons, was an effective and safe method for collapsing the reinforced concrete structure as designed.

b) The California Highway Patrol managed traffic on the water surface for extended times and on the bridge roadway during the brief blast events extremely well and with minor inconvenience to the traveling public, both on the water and on the bridge.

c) The Blast Attenuation System (BAS) was effective in significantly reducing the amplitude of the propagating pressure/noise wave generated from the blasts within the concrete structure.

d) The results of the caged fish studies demonstrated without a doubt that the blast plan design and BAS combined to tremendously reduce the threat to fish.

e) The movements measured on nearby structures including the Bay Area Rapid Transit's Transbay Tube and the East Bay Municipal Utility District's sewer outfall were very small and well below their capacities to perform in large earthquakes and there are no technical reasons to continue to instrument them during future blast events.

f) The timing for conducting the implosions, during the fall months (September-November), effectively demonstrated the success of seasonal windows to minimize and avoid impacts to multiple species.

g) The marine mammal sensitivity threshold boundaries and observers were effective in protecting the marine mammal species in the vicinity of the implosions.

h) The use of air/sound cannons seemed to be effective for seagulls and common SF Bay bird species, but there were no diving brown pelicans or least terns nearby at the time of the blast events.

i) Following the blast events, water quality conditions in the SF Bay returned to background conditions sooner than predicted. Turbidity and dissolved oxygen measurements showed their levels did not significantly change from the background levels. The pH levels returned to background conditions within thirty minutes to a few hours. There were no changes to bay water conditions at the eelgrass beds near Treasure Island and Alameda Island.

j) Sonar surveys of the foundations removed indicate that sedimentation of pre-existing scour holes is occurring as anticipated.

k) In the case of relatively smaller remaining piers to be imploded in the future, there is opportunity to implode multiple piers during the same blast event, with less environmental impacts to SF Bay.

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PERSONAL COMMUNICATION

Zahniser, D. Rescue and Response Manager, Marine Mammal Center. November 2016—via email with P. Thorson (BiomaAS) regarding marine mammal stranding survey results.

Appendix

Figure A-1. Aeration Frame Design, as Presented in the APS

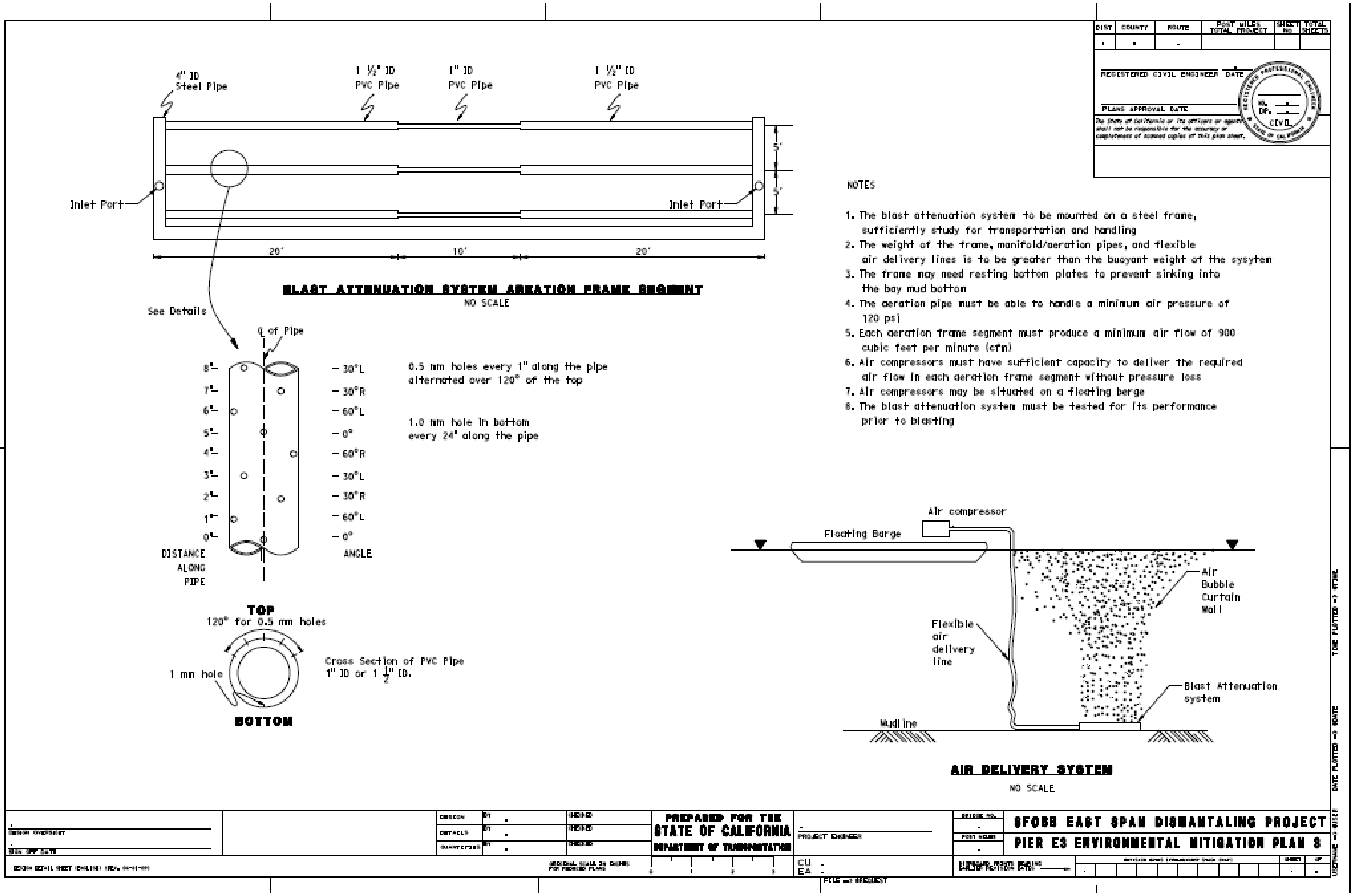
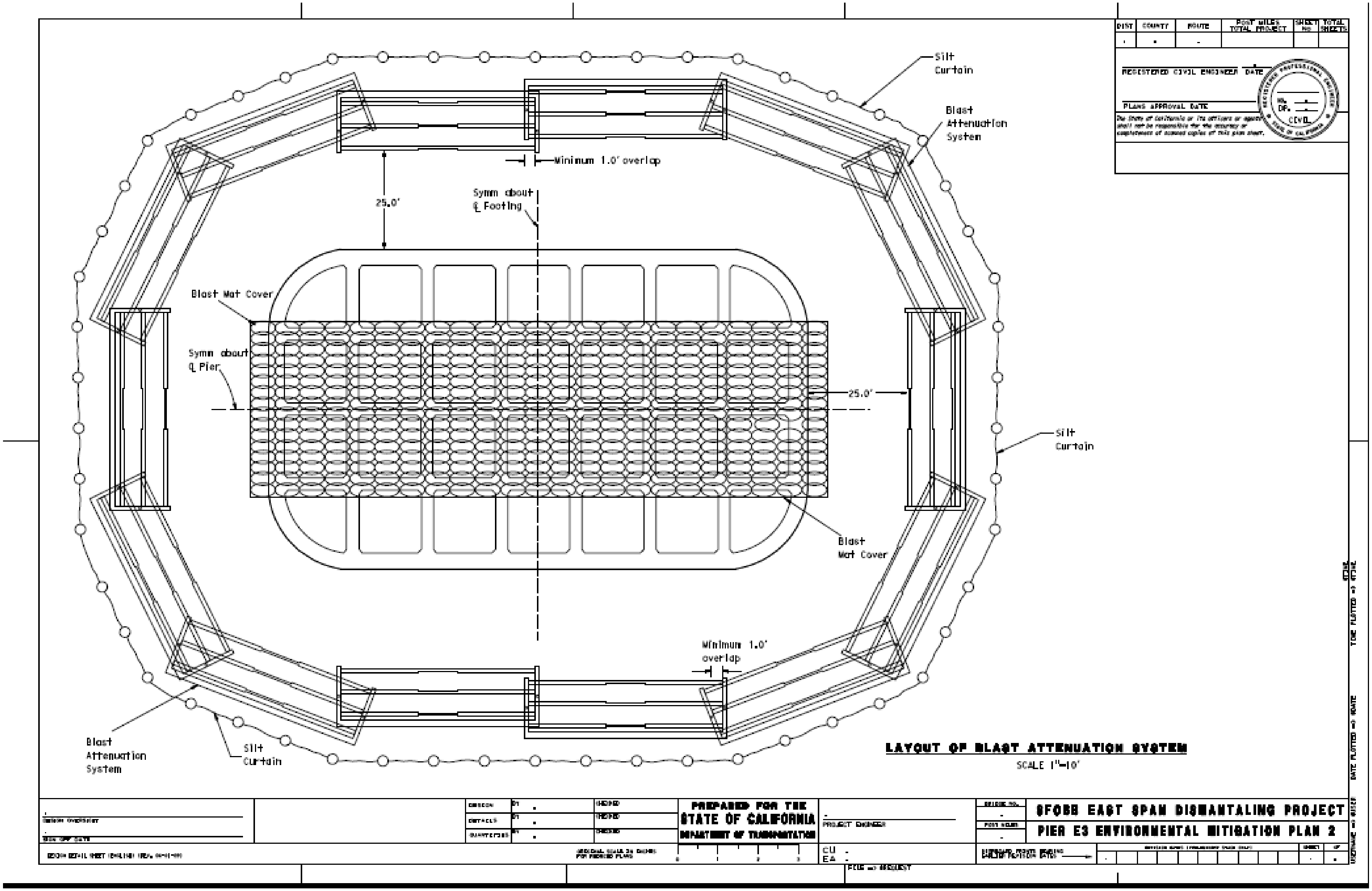


Figure A-2. BAS Frames Surrounding Pier E3, as Presented in the APS



SFOBB - Demolition Schedule (DRAFT 23-Jan-2017)